eRD6 Progress Report

EIC GENERIC DETECTOR R&D ADVISORY COMMITTEE MEETING

July 23, 2020

The eRD6 Consortium

- **Brookhaven National Laboratory (BNL) -** E.C Aschenauer, B. Azmoun, A. Kiselev, M. L. Purschke, C. Woody.
  - Barrel TPC Tracker: TPC and TPC/Cherenkov; zigzag pad readout, Avalanche structure readout.
- **CEA Saclay -** F. Bossu, Q. Huang, M. Vandenbroucke. **(new eRD6 member)**
  - Barrel MPGD Tracker: Cylindrical Micromegas Tracker;
- **Florida Institute Of Technology (FIT) -** J. Chesslo, J. Collins, M. Hohlmann, M. Lavinsky, B. Steffen.
  - Barrel MPGD Tracker: Fast μRWELL Tracking Layer;
  - End Cap GEM Tracker: Large area & low mass GEM with zig-zag readout.
- **INFN Trieste -** C. Chatterjee, D. D'Ago , S. Dalla Torre, S. Dasgupta, S. Levorato, F. Tessarotto, Triloki.
  - Particle ID: Hybrid MPGDs for RICH applications; New photocathode materials for RICH detectors.
- **Stony Brook University (SBU) -** : K. Dehmelt, A. Deshpande. P. Garg, T. K. Hemmick, A. Kulkarni, S. Park, C.L. Perez, V. Zakharov, A. Zhang.
  - Particle ID: Short radiator length RICH, Large Mirror, Meta Materials;
  - Barrel TPC Tracker: TPC-IBF
- **Temple University (TU) -** M. Posik, B. Surrow, N. Lukow, A. Quintero.
  - Barrel MPGD Tracker: Fast μRWELL Tracking Layer;
  - End Cap GEM Tracker: Commercial GEMs.
- **University Of Virginia (UVa) -** K. Gnanvo, N. Liyanage.
  - Barrel MPGD Tracker: Fast μRWELL Tracking Layer
  - End Cap GEM Tracker: Large area GEM with U-V readout.
- **Yale University -** D. Majka*, N. Smirnov.
  - Barrel TPC Tracker: : Avalanche structure readout

Outline

- **End Cap Tracker:** GEMs
- **Barrel Fast Layer:** Cylindrical uRWELL
- **Barrel MPGD Tracker:** Cylindrical Micromegas
- **Barrel Tracker:** TPC
- **Particle ID**
  - R&D on Hybrid MPGDs for RICH.
  - Studies of New Photocathodes for RICH.
  - Development on Large Mirror for RICH.
  - Studies of Meta Materials.
- **eRD6 Budget request for FY21**

*** Deceased**

eRD6 Progress Report: Contribution to the Yellow Report

eRD6 consortium is playing an important role in the elaboration of the EIC Yellow Report (YR) document with contributions to several YR Working Groups (WGs), in particular Tracking and PID WGs. The developments performed within eRD6 activities are injected as input to the relevant WGs, often accompanied by a dedicated effort to shape the information in a form adequate for the Yellow Report initiative. This core effort is accompanied by personal contributions from all eRD6 members:

- **Silvia Dalla Torre** *(INFN Trieste)* is **convener of the YR Detector Working Group** (YR-DWG) overlooking the broad discussions related to the various EIC detector options under consideration including the detector integration and the complementarity aspects of different detector options. Her role as convener is complemented by her contribution to the discussions in WGs: PID, DAQ and electronics, integration and central magnet.
- **Kondo Gnanvo** *(University of Virginia)* is **co-convener of the Tracking WG,** one of the subgroups of the YR-DWG. He is specifically looking at all the aspect of gaseous detectors options including MPGDs technologies for EIC central tracking detector which include both the barrel and both end cap trackers.
- **Thomas Hemmick** *(Stony Brook University)* is **co-convener of the PID WG**, one of the subgroups of the YR-DWG. He is dedicating specific effort to the comparative analysis of the several technologies proposed in order to perform PID from the low momenta (1 GeV/c) up to the high ones (50 GeV/c).
- **Alexander Kiselev** *(Brookhaven National Lab)* is **co-convener of the integration and central magnet WG,** one of the subgroups of the YR-DWG. Among other efforts, he has built a software tool for fast modelling and generation of EIC Central Detector templates.
- **Matt Posik** *(Temple University) is the* **liaison between eRD6 and the YR WGs** including physics (PWG), detector (DWG) and software (SWG).

eRD6 Progress Report: Impact of COVID-19 on Activities

- The COVID-19 pandemic and subsequent lockdown has affected all activities within the eRD6 consortium, though the severity of the impact varies as a function of the geographical location and the nature of the activities and type of institutions (national lab or universities)
- A breakdown detail of the impact for each group is provided in the backup slides

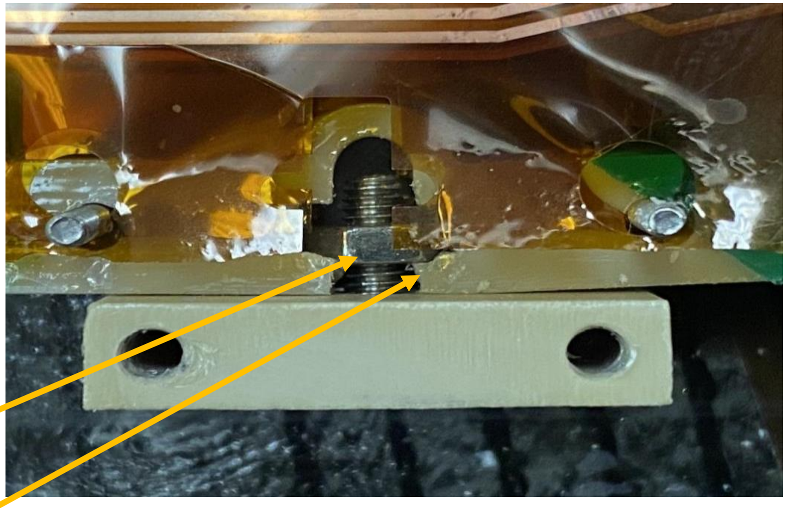
End Cap GEM Tracker

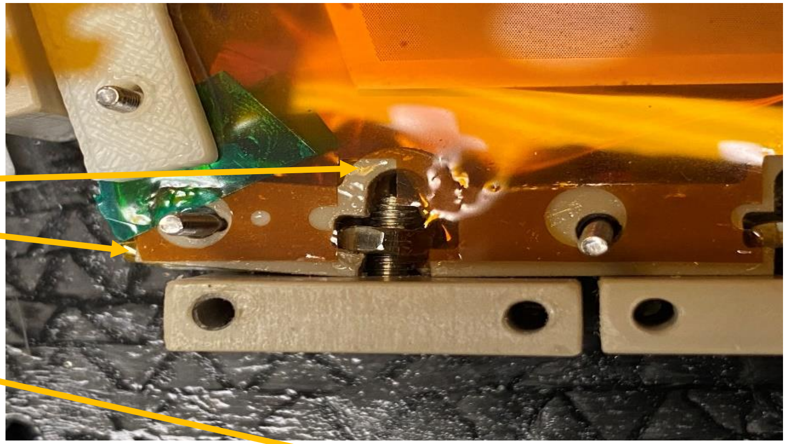
End Cap Tracker: GEM with Carbon Fiber Frame @ FIT

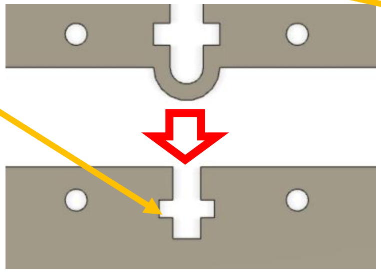
Refurbish Inner Frame Assemblies:

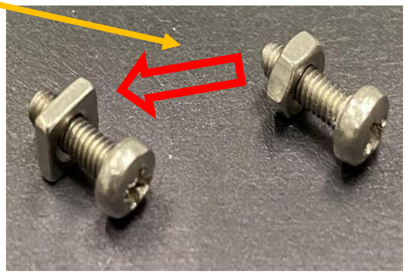
- **The problem:** Persistent shorts between GEM foils observed
- Attempted remedy with Temple U. Kapton rings b/w foils not successful
- Insufficient foil tension causes shorts
- Components in the fully mechanical construction identified as weak spots:
  - ➪ Embedded hex nuts rotate
  - ➪ 3D-printed inner frame pieces
    - abraded by rotating nuts
    - bent due to arches

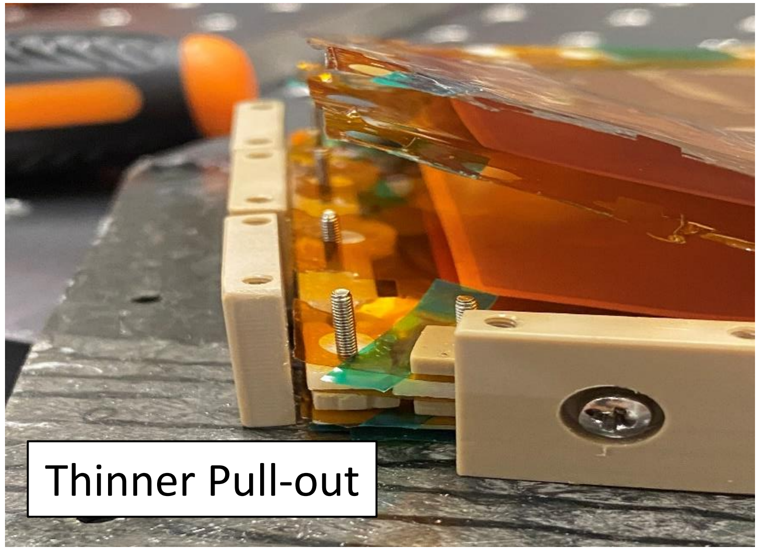
- **Remediation in Progress:**
  - ➪ Replace hex nuts by square nuts
  - ➪ Redesign inner frames
    - Replace arches with straights
    - Tighten cut-out tolerances
  - ➪ Replace all ABS with PEEK material
  - ➪ Make pullouts thinner to increase margin for stretching foil (on right)

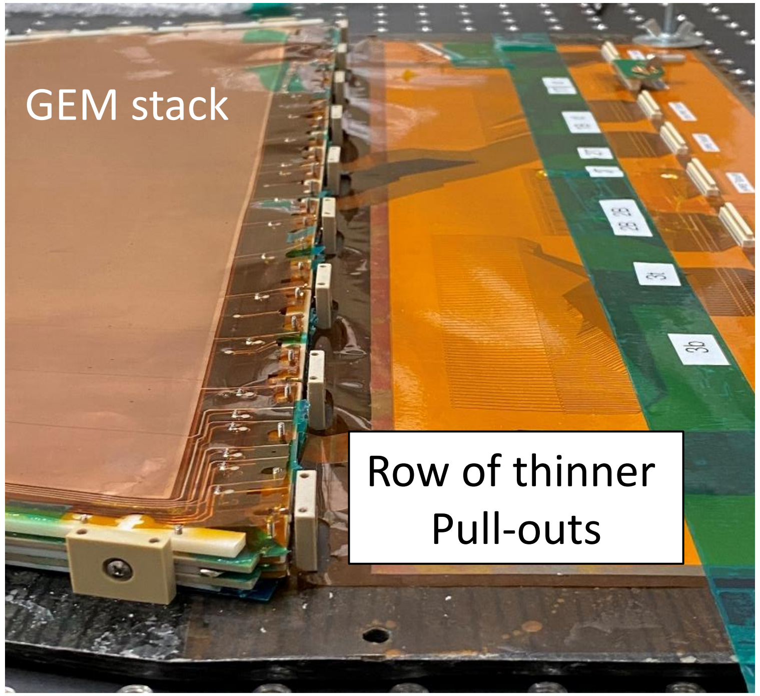




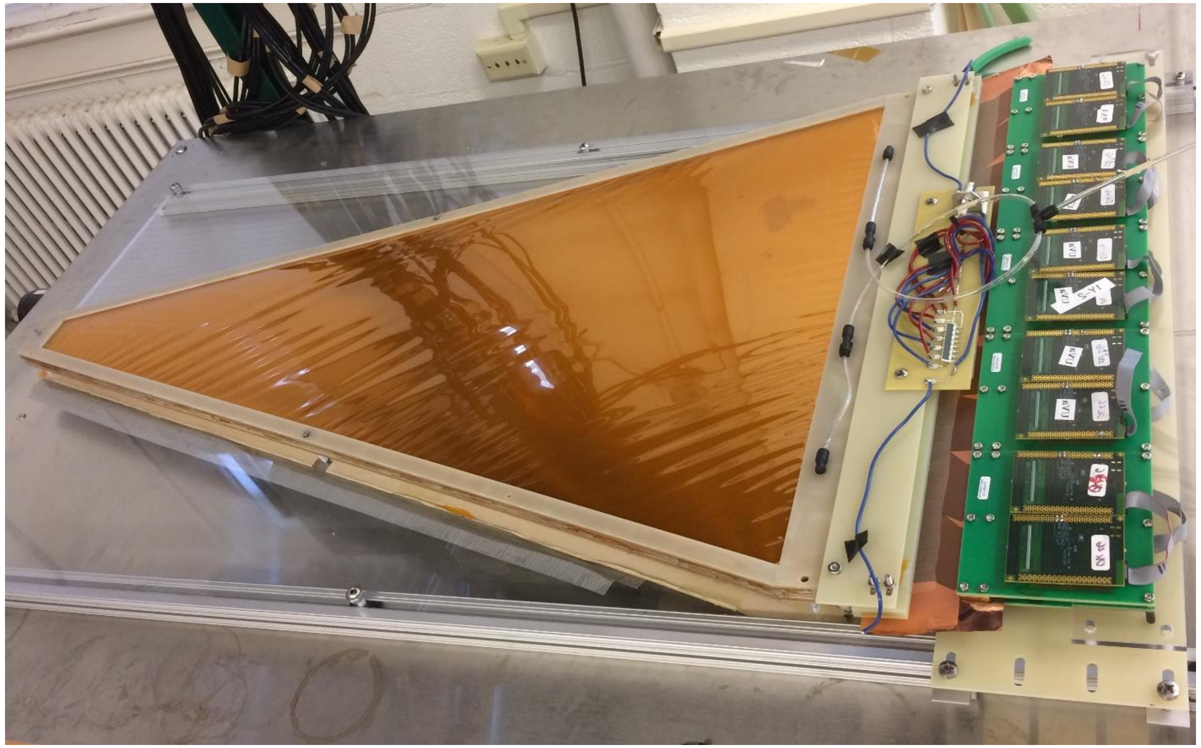








End Cap Tracker: Large GEM with 2D U-V Strip @ UVa



What was planned

- ❑ Test different sets of zebra strip to select the best option that improve the detector signal response
- ❑ Finalize the fix to the collapse of the gas window / drift cathode
- ❑ **Not much was done because of the COVID-19 situation**

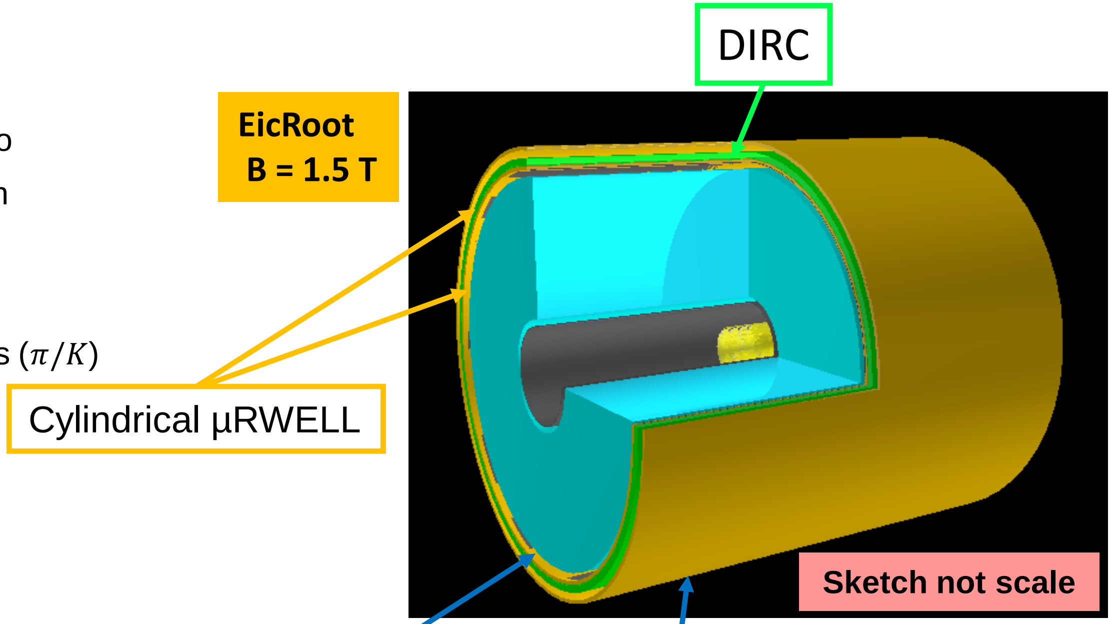
Plans for FY21 cycle

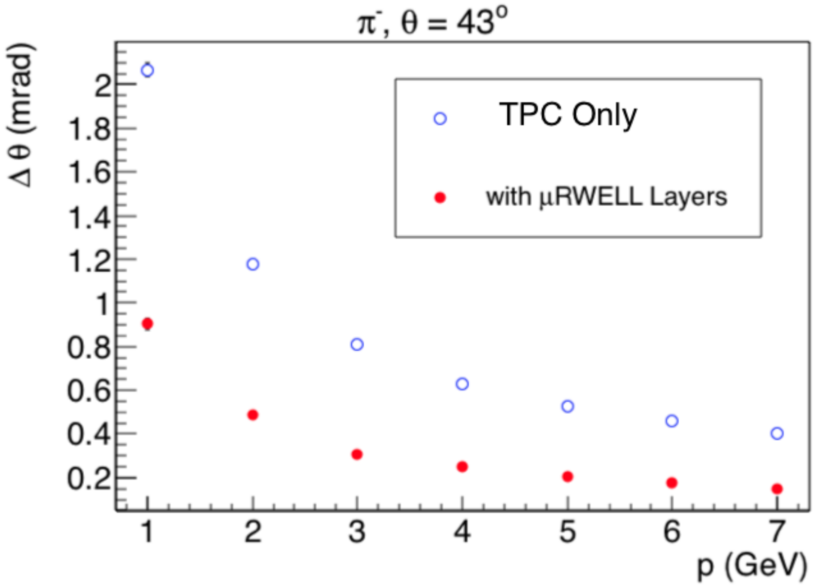
- ❑ Procure different types of zebra strips to test on the prototype
- ❑ Finalize the fix for gas window / drift foils & re-test with x-ray
- ❑ Test the prototype in test beam at FTBF Fermilab this Spring 2021
  - ➩ Complete the spatial resolution studies
- ❑ Plan is to complete the R&D on large GEM by January 2022

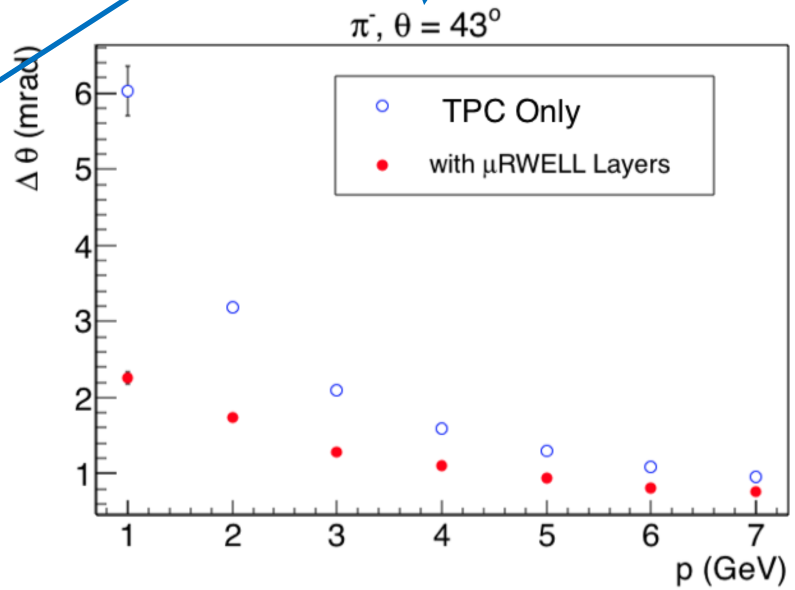
Barrel Fast Tracking Layer: Cylindrical µRWELL

Barrel Fast Tracking Layer: Simulation of Cylindrical μRWELL

- **Cylindrical μRWELL layers:**
  - Located just before and after the PID detector (DIRC)
  - Provides precision space point and directional track vectors outside of the TPC field cage to counteract multiple scattering in the field cage to help with seeding the DIRC reconstruction
  - Provide high resolution space point for TPC calibrations
  - Provide fast tracking for bunch crossing ID for a TPC+ MAPs like configuration
  - Improved angular resolution of the track can be used to increase PID separation of hadrons (π/K)
- **EicRoot Simulation**
  - Simulated detectors: SVTX, TPC, and μRWELL cylindrical layers
  - No support structure for μRWELL
  - Angular resolutions compare projected track to truth value
  - Preliminary simulations show about three times better angular resolution

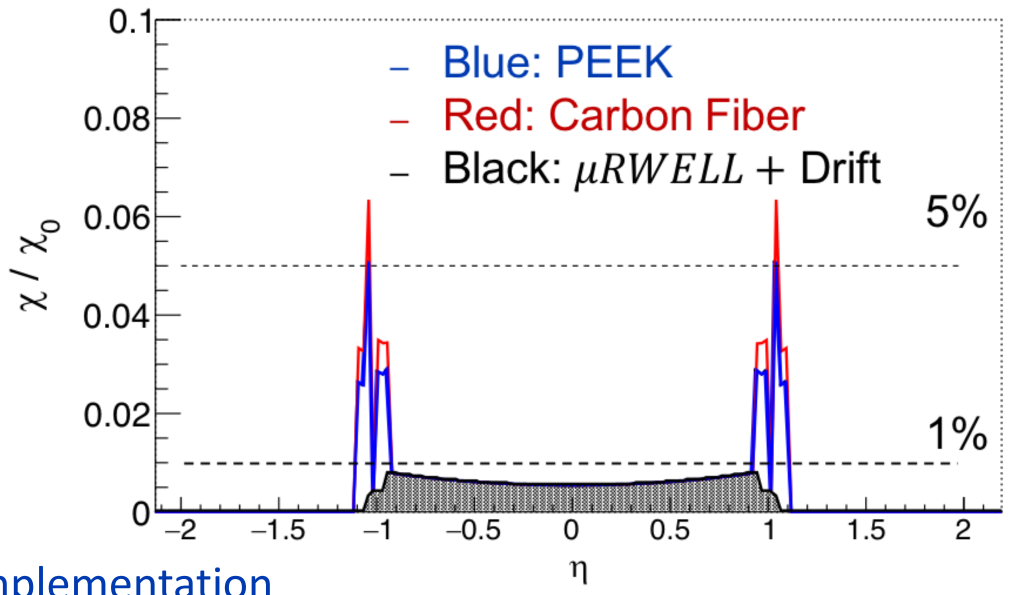






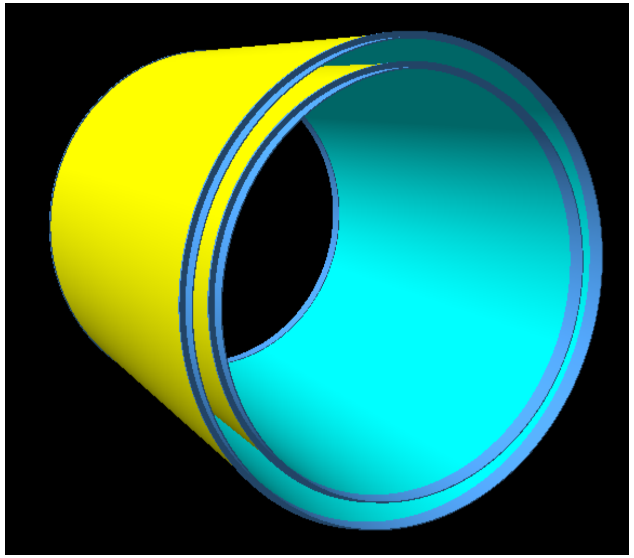
Barrel Fast Tracking Layer: Simulation of Cylindrical µRWELL

- **Cylindrical µRWELL layer Fun4All Implementation**
  - ➪ Implemented cylindrical µRWELL and FIT support structure rings into simulation
  - ➪ Detectors placed at radial (inner) locations of 79.5 cm and 90 cm
  - ➪ Material scan shows most of material budget coming from support rings
  - ➪ **PEEK** and **Carbon Fiber** materials show similar budget



FIT mock prototype

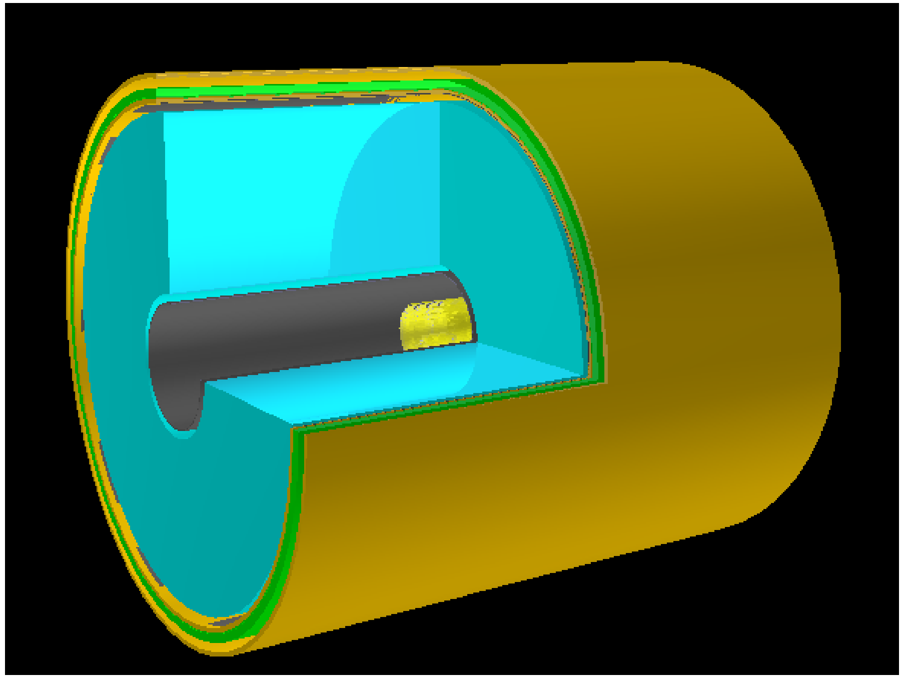
Simulation implementation



Barrel Fast Tracking Layer: Simulation of Cylindrical µRWELL

❑ Future Plans

- ➪ Reproduce EicRoot studies in Fun4All
- ➪ Realistic implementation of µTPC mode
- ➪ Integrate central and forward tracking simulations for full performance assessment
- ➪ 10 cm x 10 cm µRWELL with 1.5 cm drift gap ordered from CERN
  Expected delivery date late August/ early Sept.

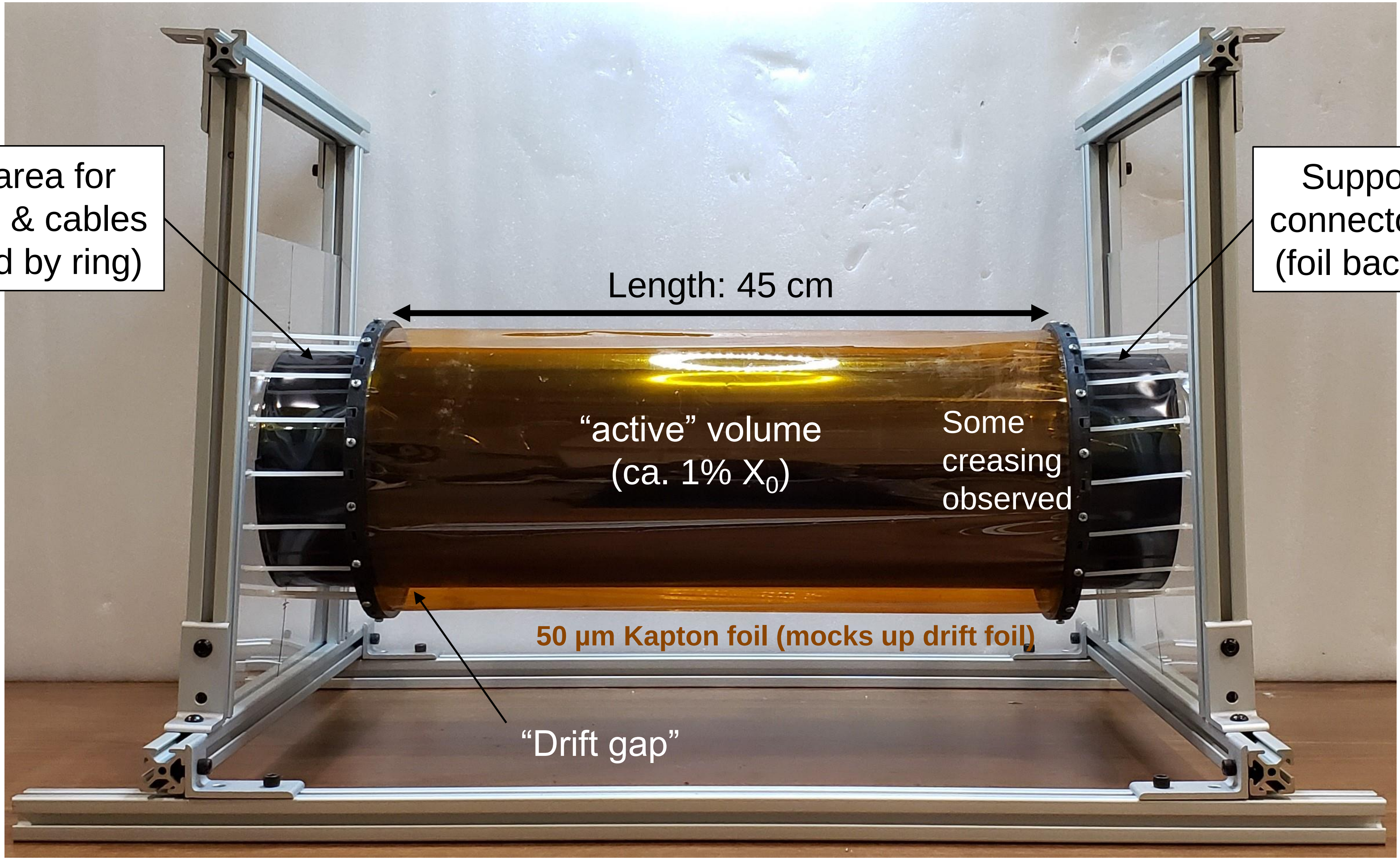


FLORIDA TECH

Barrel Fast Tracking Layer: Cylindrical μRWELL @ FIT

Mechanical Mock-up – First Full Assembly:

Support area for connectors & cables (foil backed by ring)



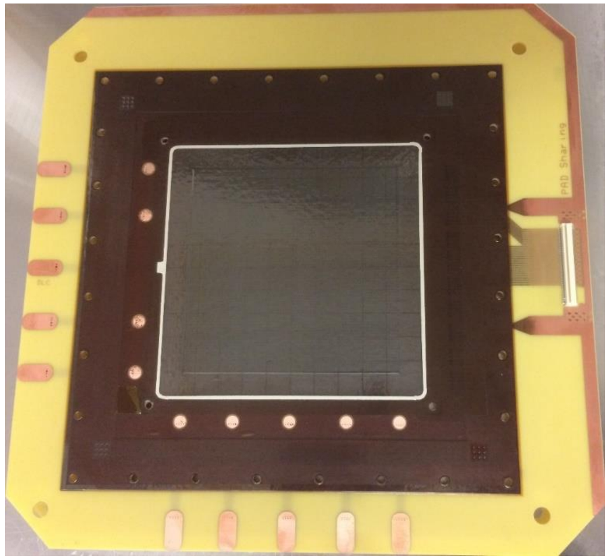
Support area for connectors & cables (foil backed by ring)

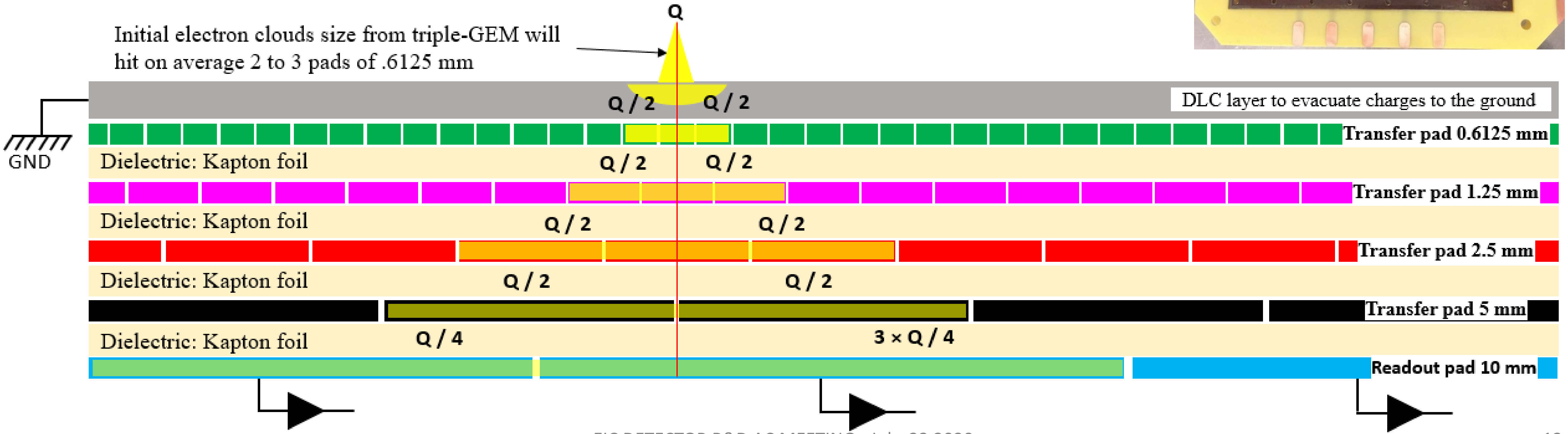
Barrel Fast Tracking Layer: Capacitive-Sharing Pad Readout @ UVa

Principle of capacitive-sharing large-pad Readout

- Vertical stack of pads layers ⇨ Transfer of initial charge from MPGD by **capacitive coupling**
- Space arrangement of the pads and doubling pad size from one layer to the one below allow:
  - ⇨ the preservation of the spatial resolution performance (expected better than 100 µm for 1 cm^2 pad readout)
  - ⇨ significant reduction of number of electronic channels to be read out
- Low cost and highly flexible readout technology
  - ⇨ Suitable to a variety of applications related to EIC detector R&D programs

large-pad readout prototype @ UVa





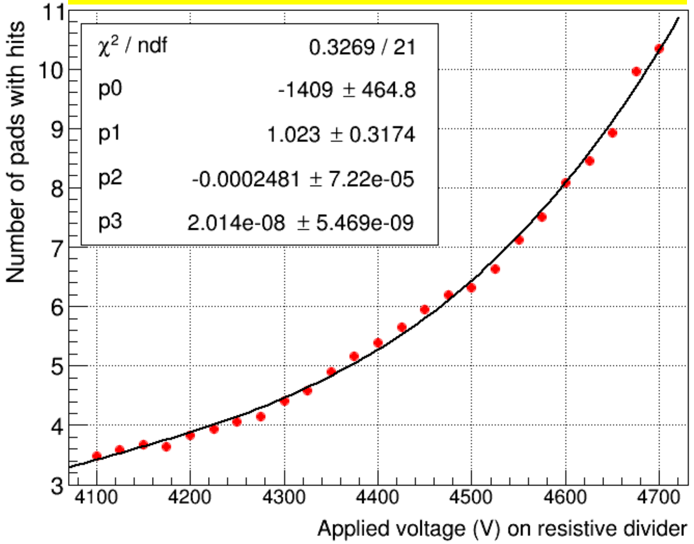
Barrel Fast Tracking Layer: Capacitive-Sharing Pad Readout @ UVa

Triple GEM prototype with capacitive-sharing large-pad readout in x-ray setup

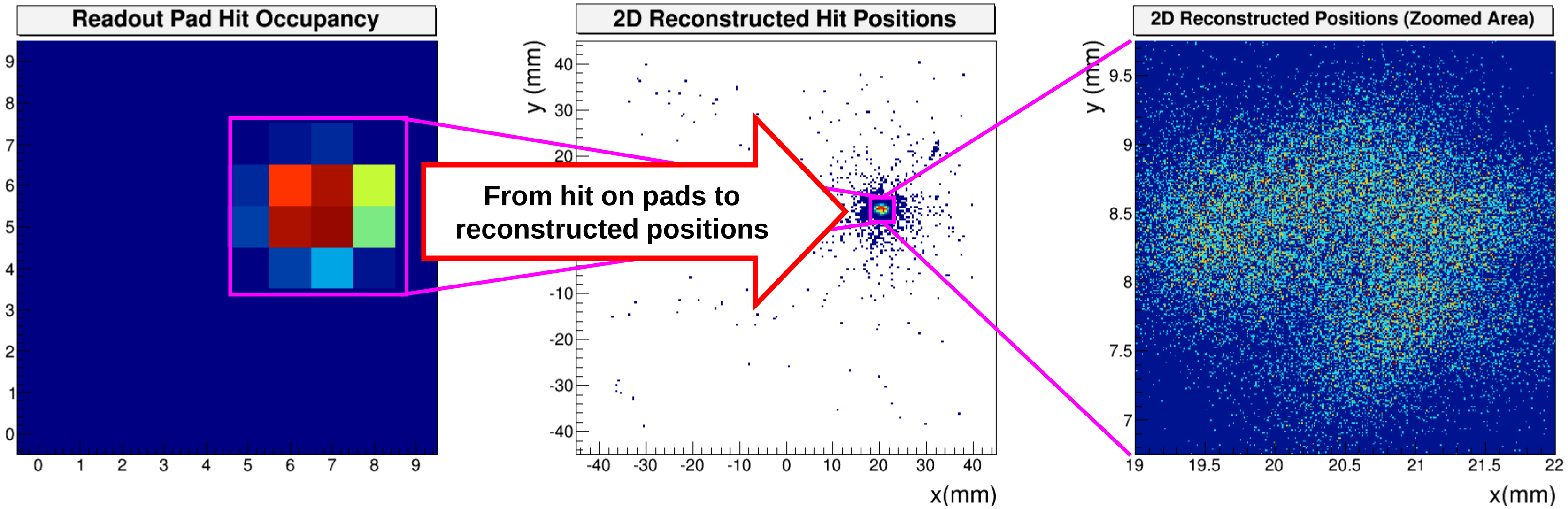
Some preliminary results with x-ray test

- Average pad hit occupancy: 3 × 2 pads ⇨ average beam size spread on pads over an area of 3 cm × 2 cm
- Reconstructed beam spot: 3 mm × 3 mm ⇨ size ratio = 67
- Uniform distribution of hits: histogram bin size: 10×10 μm^2
  ⇨ No pattern correlated to the pad RO geometry so we expect an excellent resolution performance
- Center of gravity (COG) for position reconstruction

Cluster size vs. HV on divider



Pad Occupancy & 2D hit reconstruction

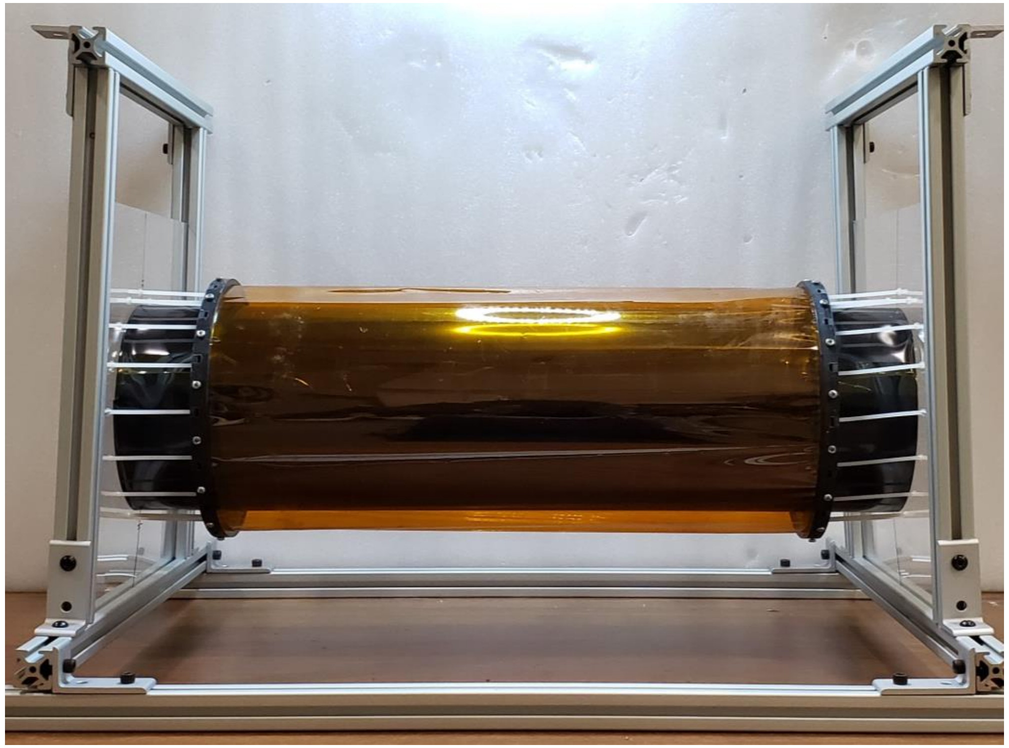


UVa R&D Plans for capacitive-sharing readout

- Optimization of readout pad size ⇨ 1 cm^2 to 4 cm^2 for Cylindrical µRWELL prototype
- Explore ideas to minimize the pad capacitance noise and study cross talk effect
- Study linearity and spatial resolution of different pads parameters in x-ray scanner @BNL
- Study performances with several prototypes in energy proton beam (12 GeV) beam at FNAL

Barrel Fast Tracking Layer: Plans for FY21 Cycle

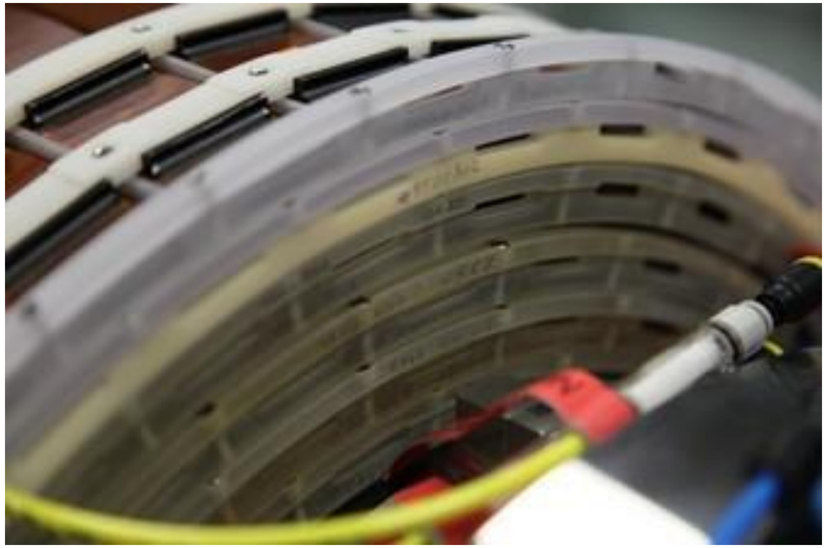
- Design and assembly of fully functional cylindrical µRWELL detector prototype:
  - Joint R&D effort between Florida Tech. Temple U. & UVa
  - **FIT:** Design, construct, and test prototype mechanics
  - **UVa:** Design the µRWELL amplification, cathode foil and readout layer
  - **Temple U:** In charge of the FE readout electronic & DAQ
- Characteristics of the proposed prototype:
  - **Dimensions:** length = 50 cm, diameter = 20 cm ⇨ full cylindrical prototype
  - **Ionization & drift volume:** 1 to 2 cm to allow operation in µTPC mode
  - **Readout choice:** Capacitance-sharing pads, standard U-V strip or combination of both
  - **FE readout:** Explore best available option from APV25, SAMPA, VMM3, DREAM
- Proposed timeline:
  - **Fall 2020 - Spring 2021:** Design and procurement of the parts
  - **Spring 2021 - December 2021:** Assembly & preliminary characterization of the prototype
  - **January 2022 – July 2022:** Perform full characterization in test beam at Fermilab
  - **July 2022:** Presentation of final test beam results at EIC Detector R&D meeting
  - **December 2022:** Submission of results in peer-reviewed paper



Barrel MPGD Tracker: Cylindrical Micromegas

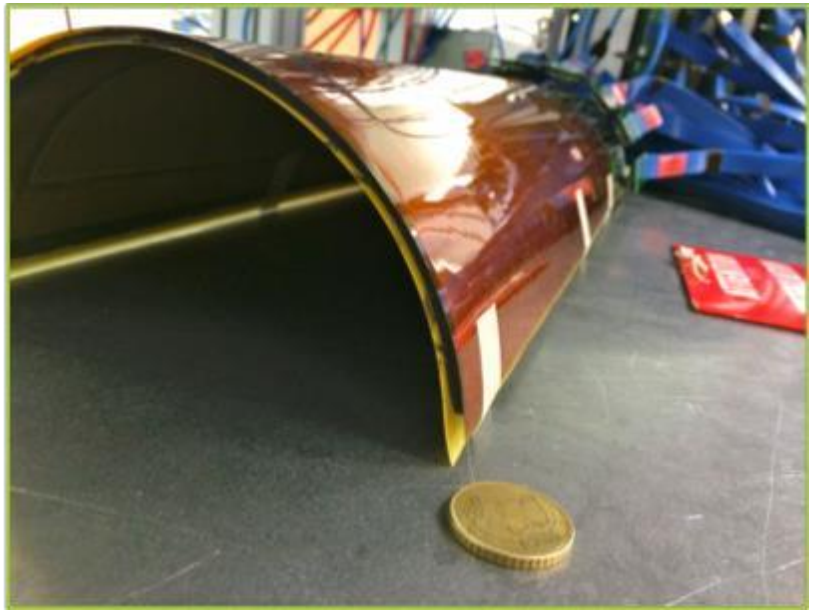
Barrel MPGD Tracker: Cylindrical Micromegas @ CEA Saclay

- Focus on a barrel tracker as possible alternative to the TPC
- Concentric cylindrical layers of Micromegas detectors provide a low material budget (~0.3% X_0 per layer) compact design
- Curved Micromegas are already in use in CLAS12 and ASACUSA
- Simulation studies (1 post-doc Q. Huang) of a full barrel tracker ongoing (next slides)



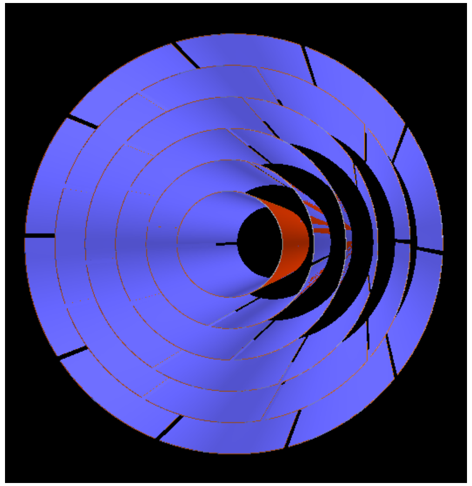
Next steps:

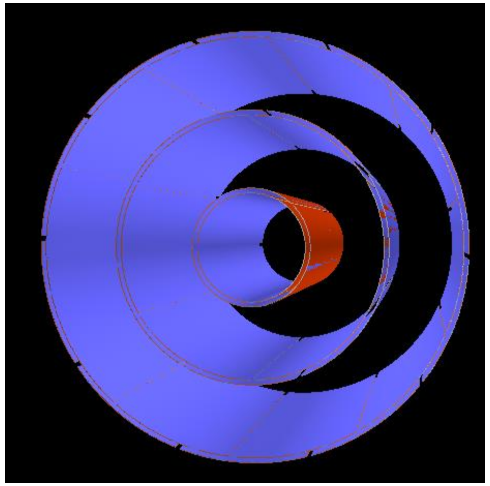
- Study light mechanical structures for supporting the Micromegas tiles
- Study different patterns for the 2D readout in terms of spatial resolution, number of readout channels and material budget:
  - ⇨ Finalization of studies on zigzag patterns (in collaboration with SBU & BNL)
  - ⇨ Test the capacitive-sharing & large-pad readout design proposed by UVa team with Micromegas

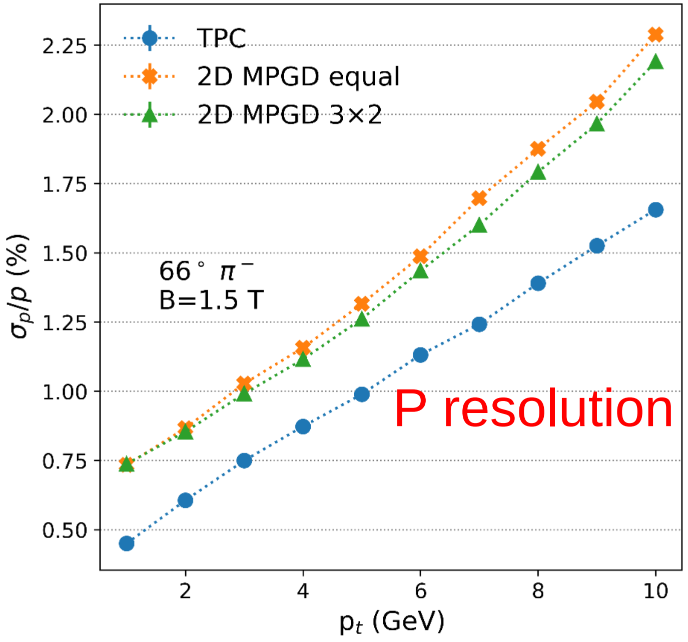


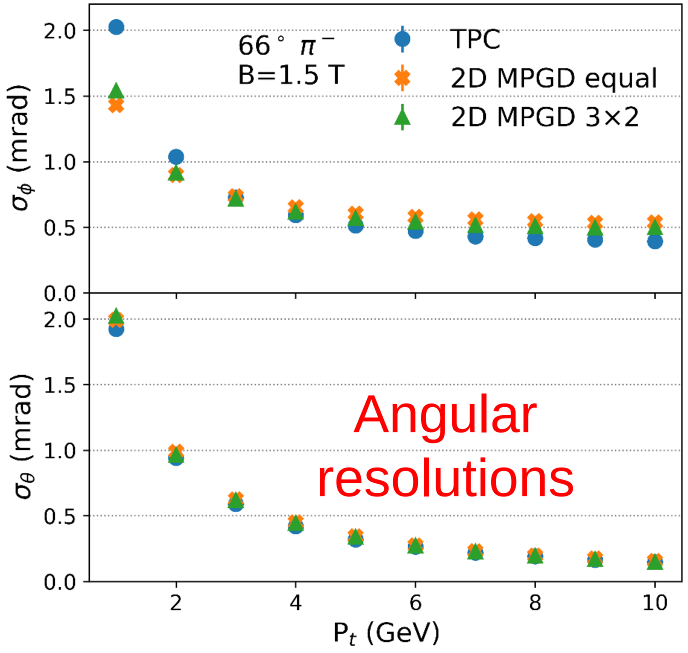
Barrel MPGD Tracker: Cylindrical Micromegas @ CEA Saclay

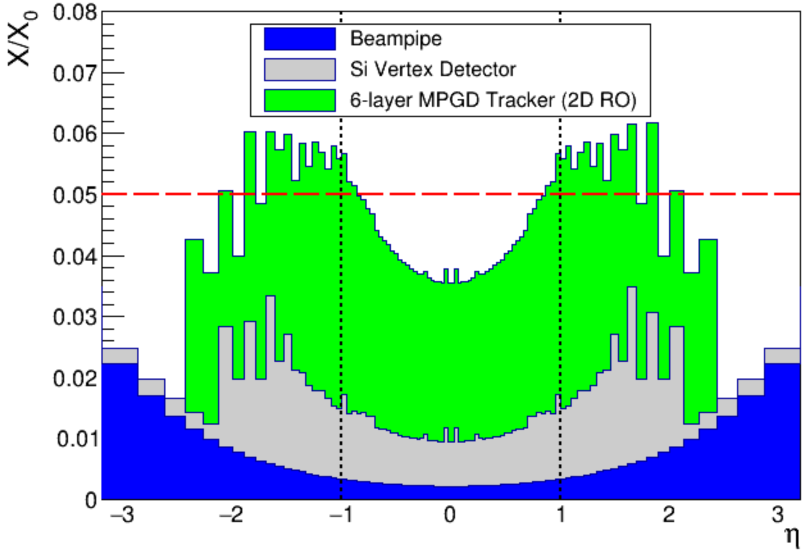
- Simulation based on Fun4All + ePhenix
- A 6-layer MPGD cylindrical tracker is set up for particle tracking
  - ➪ 2 configurations tested: equidistant vs. 3 groups
- Material budget and tracking performance have been investigated through simulation
  - ➪ Material budget < 5% in the central region
  - ➪ Momentum resolution slightly worse than the TPC's
  - ➪ Angular resolutions similar to the TPC's









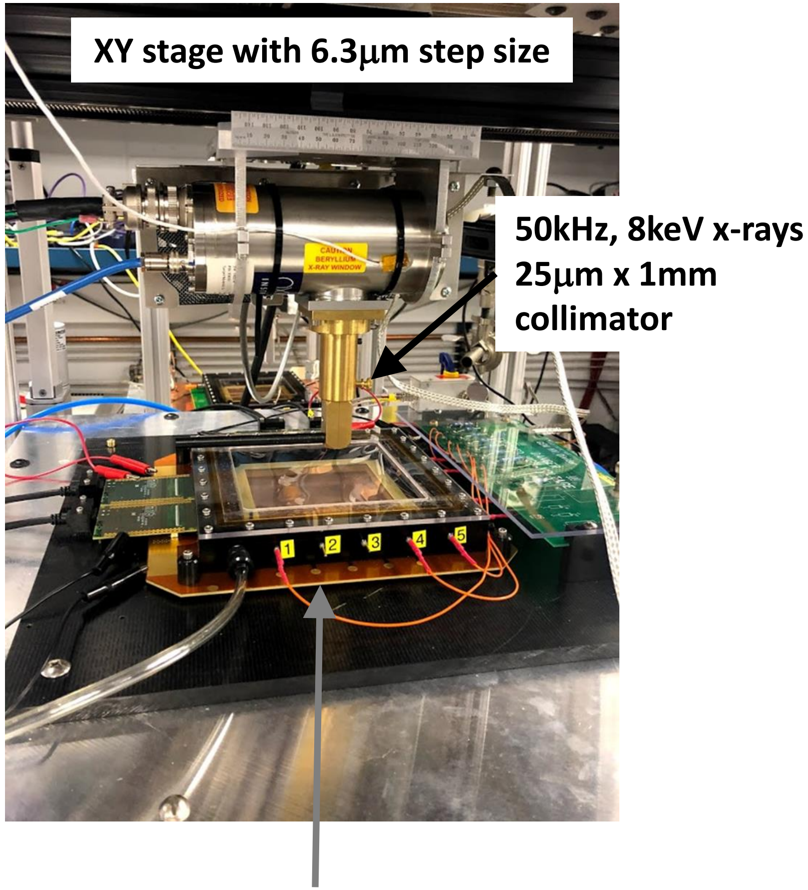


Q. Huang

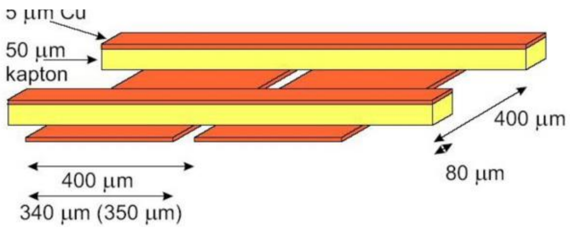
Barrel Tracker: TPC

Barrel Tracker: TPC R&D @ BNL

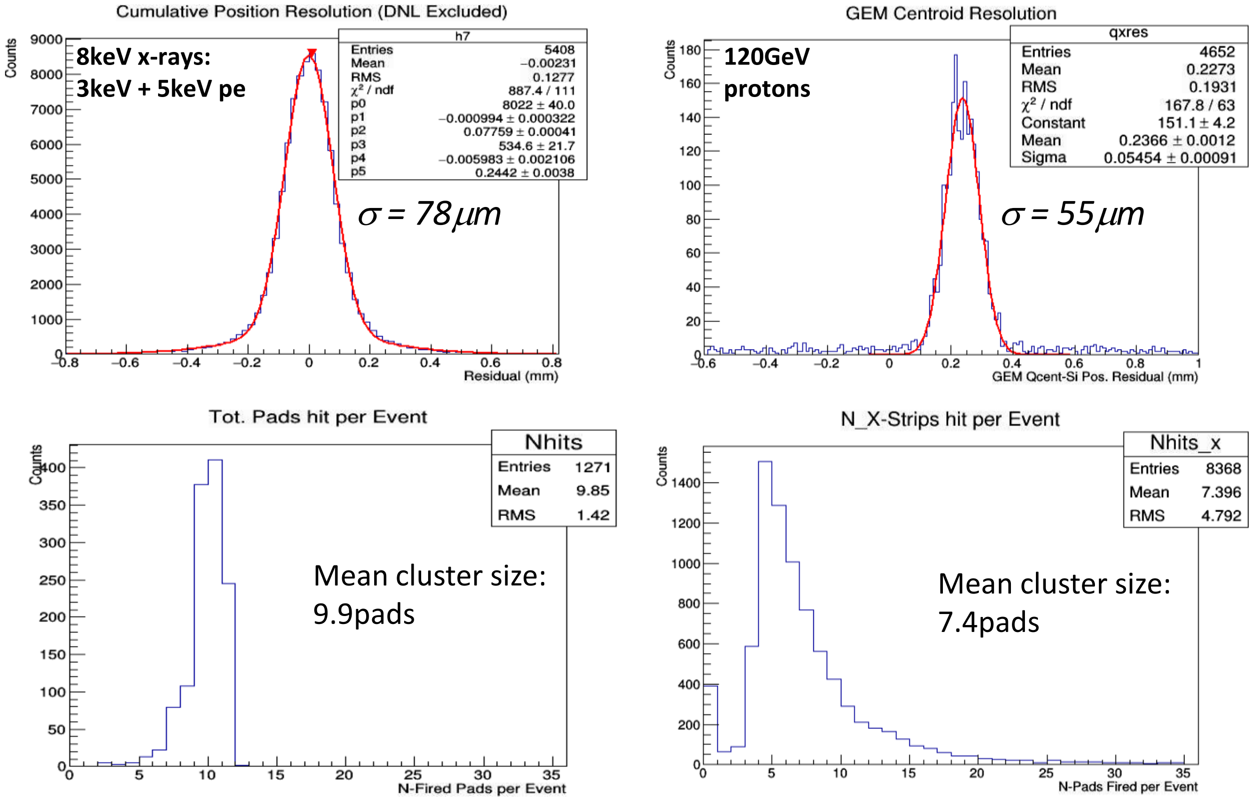
Characterizing New Collimated X-ray Source



COMPASS 2D Microstrip r/o



Detector Performance: x-ray Vs test beam

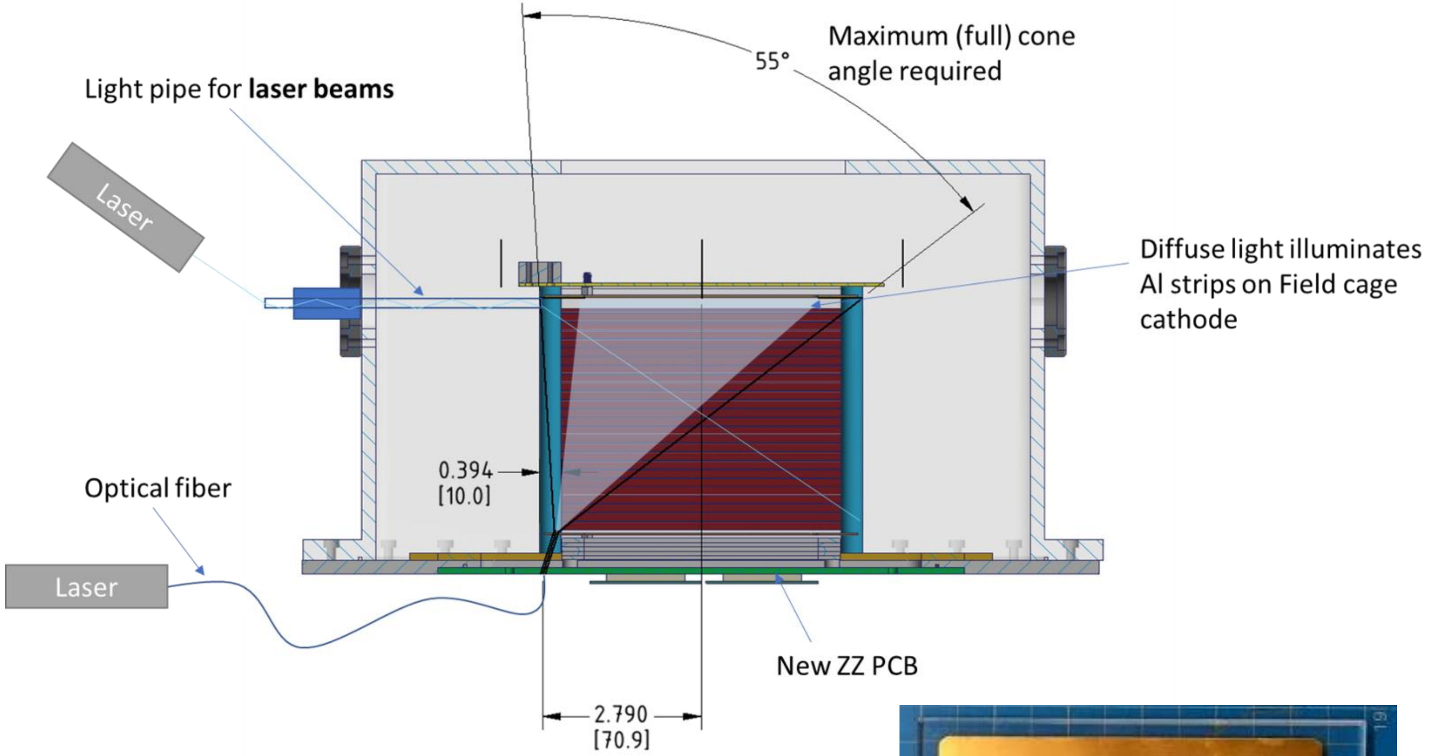


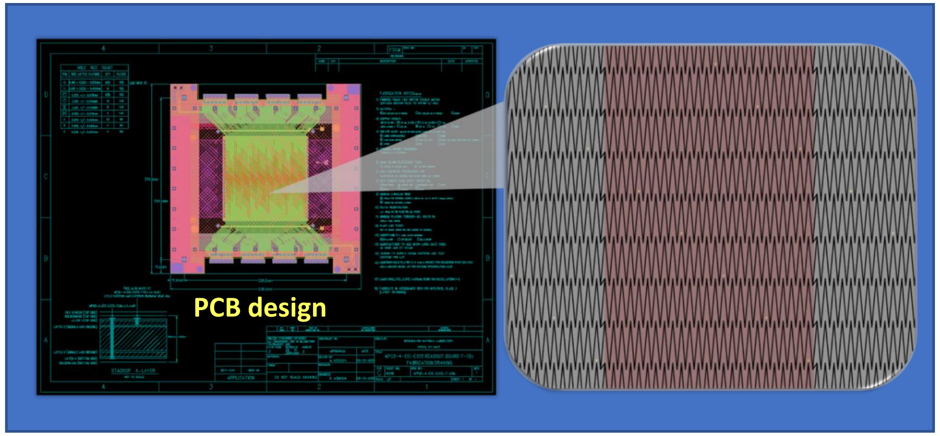
- ❑ Measured spatial resolution is substantially better for the test beam results: 55μm vs 78μm, and the cluster size is smaller on average: 7.4pads vs 9.9pads
- ❑ This is likely due to the relatively large range of 5keV photoelectrons in the Ar + 30% CO2 operating gas (>300μm), where the contribution from the collimator width should be negligible
- ❑ We plan to repeat this measurement with ~6keV x-rays, where the range of the resulting 3keV photoelectrons is <100μm

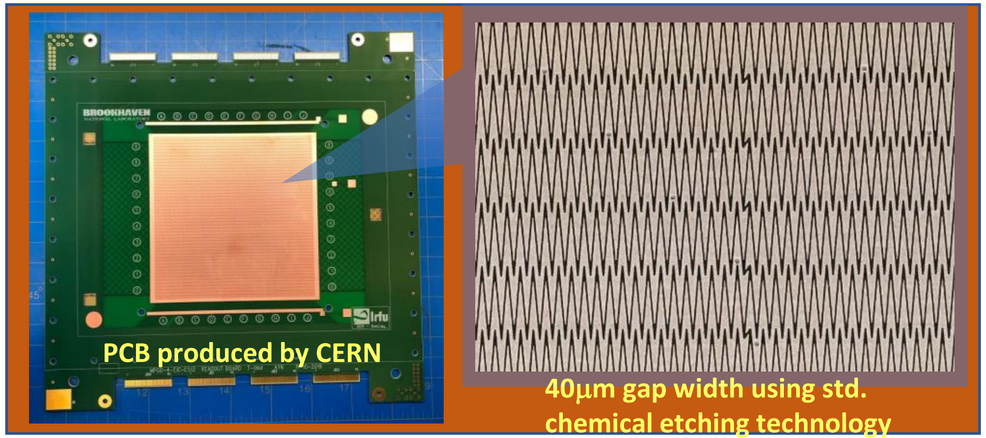
Barrel Tracker: TPC R&D @ BNL

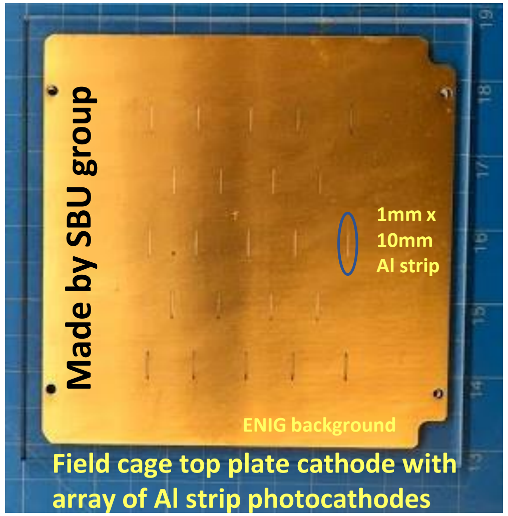
Progress on mini-TPC Prototype

- Design of new optimized ZZ pattern is complete
- Received new r/o PCB; ready to be installed
- Design of new diffuse laser source to illuminate top plate of field cage with array of Al strip PCs
- Prototype diffuse laser source used for calibration purposes
  - ➪ Test calibration scheme used in real detector
  - ➪ Measure ionization yield vs laser intensity
  - ➪ Measure uniformity of diffuse light source
  - ➪ Measure uniformity of drift velocity across acceptance





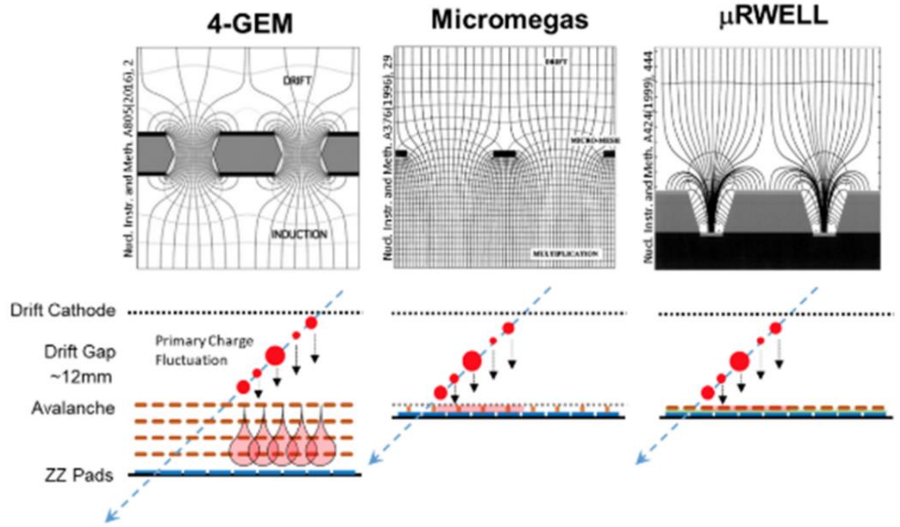


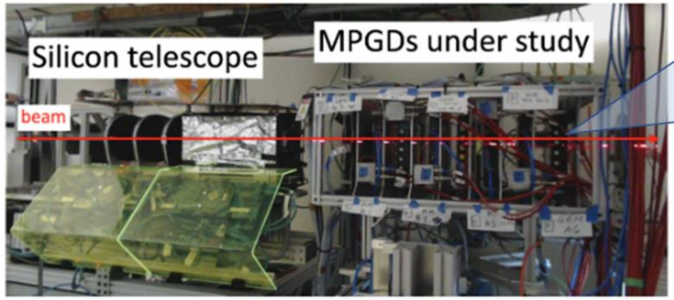


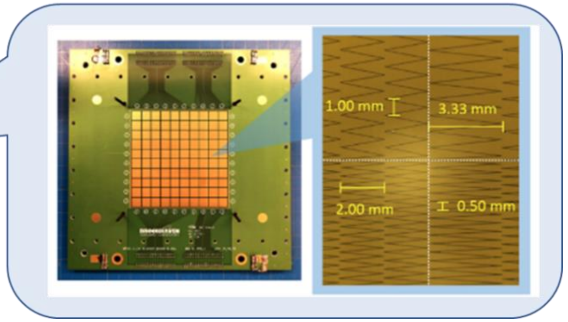
Barrel Tracker: TPC R&D @ BNL

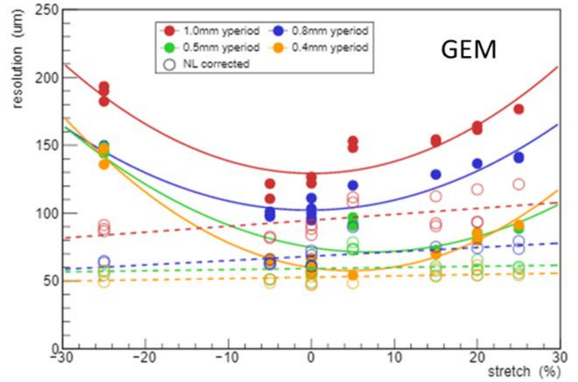
Potential readout options for a TPC, measured in a beam test

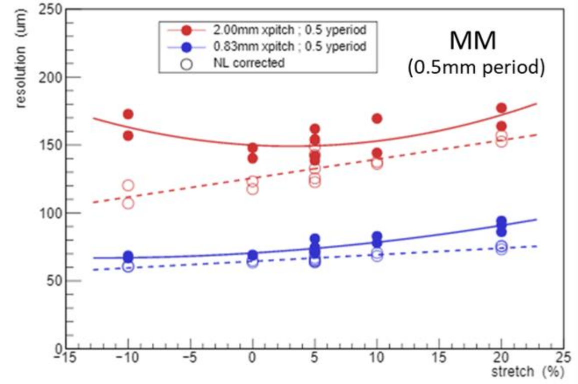
- GEM, Micromegas, and µRWELL planar detectors equipped with a variety of ZZ patterned anodes
- Tests provide a “baseline” measure of performance for each avalanche scheme and reveal optimal parameter sets (at resolution minima)
- Tests are not exhaustive since gas mixtures were not tested, nor was the field configuration optimized for each case

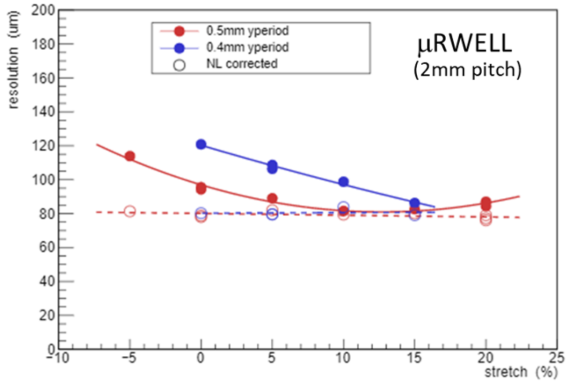








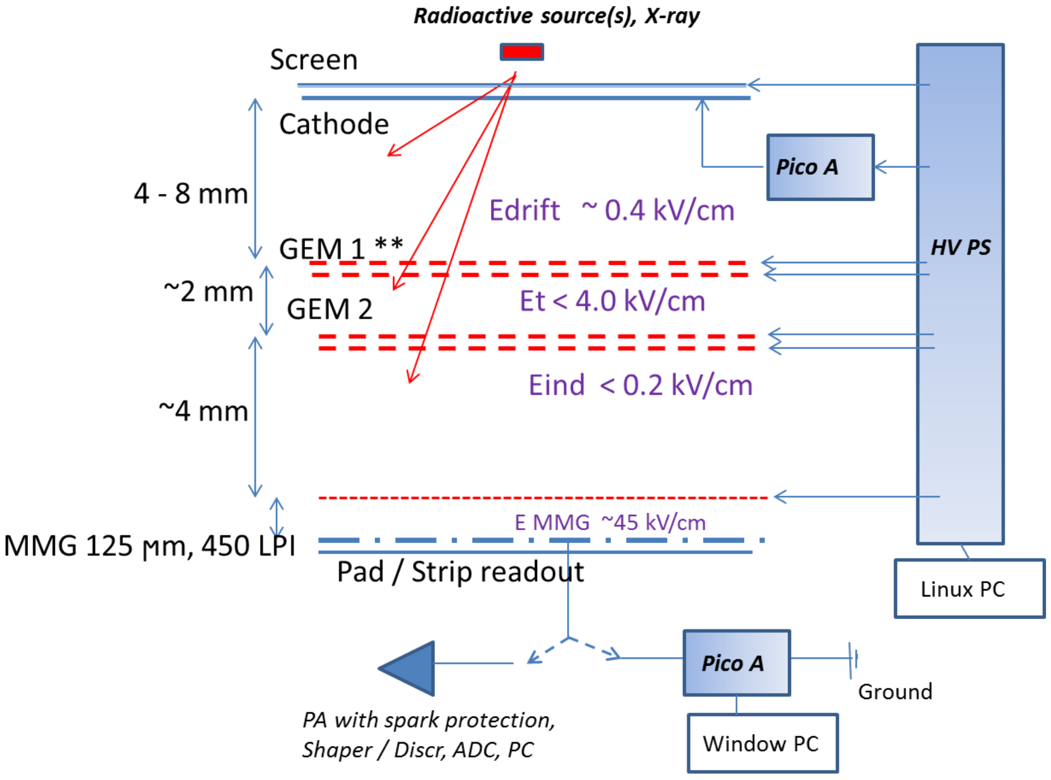


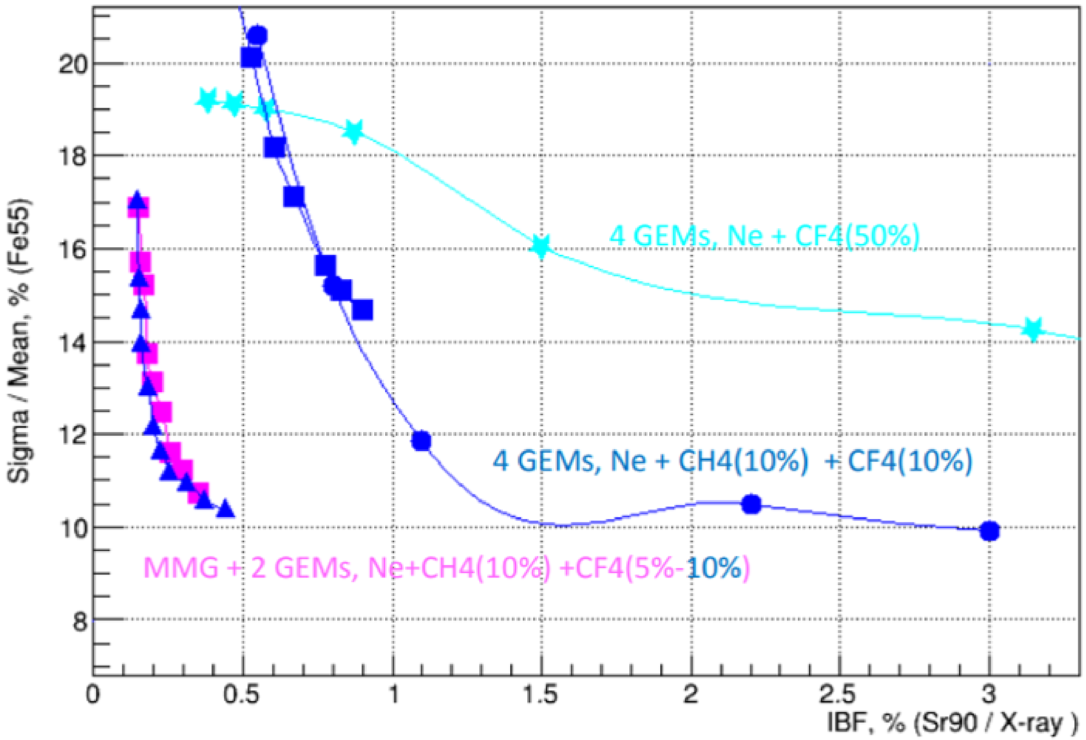


Barrel Tracker: TPC R&D @ Yale

TPC Gain Element and Gas mixtures

- Investigate gain elements (2GEM + MM, among others): attempt low IBF (in high rate environment) w/o gating grid
- Investigate gas mixtures: require reasonable dE/dx (good energy resolution), low transverse diffusion (high position resolution)





For the hybrid option simultaneously achieve IBF below 0.3% and an energy resolution better than 12% (for 55Fe x-rays at a gain of≈2000) in a variety of gas mixtures

The hybrid option is also quite robust against sparking, providing stable, continuous mode operation

** - GEM foils are in 90deg rotation position

BROOKHAVEN NATIONAL LABORATORY

Barrel Tracker: TPC R&D @ BNL & Yale

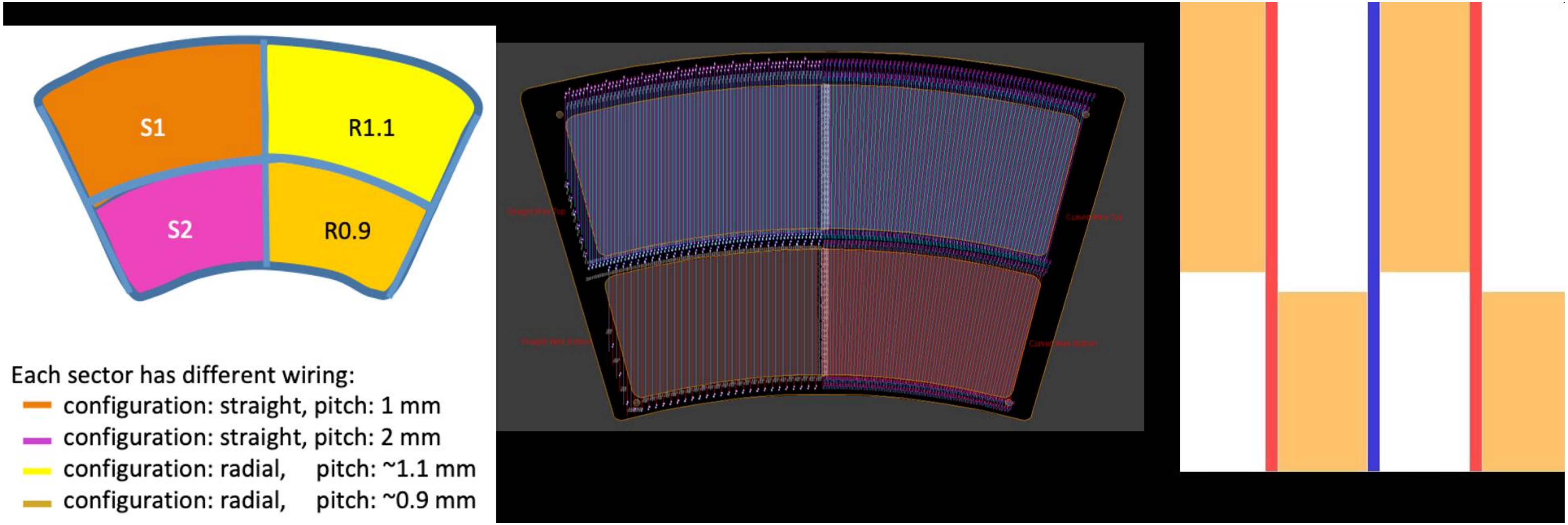
Next Steps

- A substantial portion of planned activities for the next funding cycle will include work that was not completed as a result of the shutdown due to the pandemic.
- Proposed R&D activity for the next funding cycle at BNL and Yale:
  - ➪ Baseline measurements of new TPC r/o PCB using high intensity-collimated x-ray source (x-ray scans)
    - Conduct x-ray scans to compare performance of alternate zigzag patterns + avalanche scheme (GEM, MMG, μRWELL) + working gas combinations
  - ➪ Install new zigzag PCB onto TPC prototype
    - Measure tracks produced by line laser (high statistics)
    - Compare to cosmic tracks (low statistics)
  - ➪ Procure TPC r/o PCB with Micromegas and μRWELL avalanche stage
  - ➪ Take data with DREAM and SAMPA FEEs
  - ➪ Continue investigating gas mixtures in the context of IBF vs Energy Resolution
  - ➪ Test hypothesis that the extended range of 5keV photoelectrons (>300mm) from 8keV photons are responsible for broadening the residual distributions for x-ray scan results
    - As an alternative, investigate the possibility of using laser light to provide a high precision reference point for resolution measurements
  - ➪ Design and test several new interleaved r/o anode designs intended for a photosensitive LAPPD detector

Yale University

Barrel Tracker: TPC R&D @ SBU

- Static bi-polar gating grid
  - Simulations for large parameter space
    - Wire diameter, pitch, potential across wires, various gas mixtures …
  - Test in magnetic field environment → planning test at ANL magnet facility with B up to 5 T
  - Designed PCB based pad plane with attached wires and providing appropriate potentials



Particle ID

Particle ID: the framework of the eRD6 activities in this field

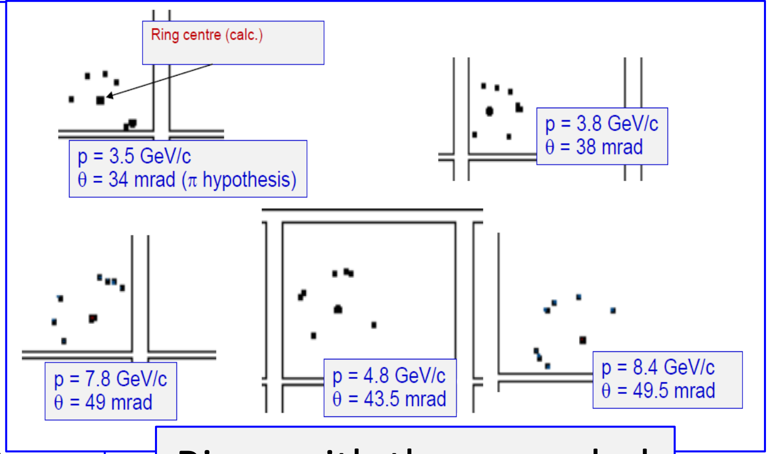
Two driving motivations

1. **Gaseous photon detectors based on MPGD technologies can play <u>a major role in PID</u> based on the Cherenkov effect:**
   - **PHENIX HBD** with triple GEM PDs *[NIMA A 646 (2011) 35]*
   - **COMPASS RICH upgrade** with Hybrid (THGEMS & MICROMEGAS) PDs *[NIMA A 936 (2019) 416]*
   - **Windowless RICH** prototype and test beam with quintuple GEM PDs *[IEEE TNS 62 (2015) 3256]*
   - **TPC-Cherenkov (TPCC) tracker** prototype with quadruple GEM PDs, developed within eRD6 *[IEEE TNS 66 (2019) 1984]*

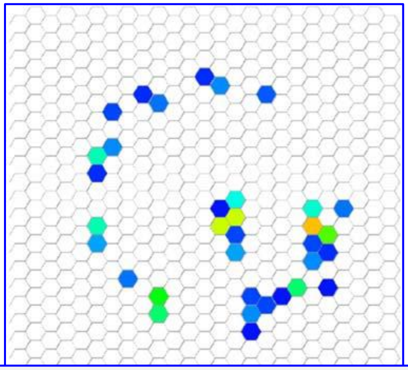
   → **eRD6 is the MPGD consortium:**
   PID development by MPGD have here their natural environment

2. **Several EIC needs in the PID sector still wait for a complete answer, in particular <u>PID at high-momentum</u>**
   - Light radiators posing requirements contradicting those of the setup compactness
   - Light-material PDs that can operate in presence of magnetic field
   - Light and effective mirrors in the UV domain

   → **The PID R&D within eRD6 aims at answering these key questions**



Rings with the upgraded COMPASS RICH



A rings with the windowless RICH prototype

Particle ID: Hybrid MPGDs for RICH @ INFN

Lab activity, therefore seriously effected by the emergency status:
No access to lab after February (hoping to resume in September)

REMINDER

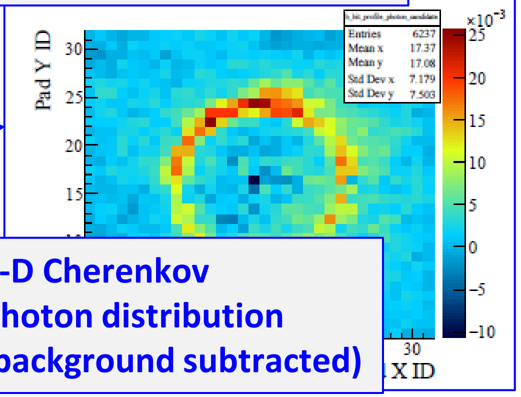
- **Prototype version1 tested in beam (results reported in July 2019)**
- **Limitation in the assessment of all the characterization figures coming from the noise level**
- Noise source analysis:
  1. From SRS architecture
  2. From detector architecture

→ ACTIONS, partially started already at the end of 2019

1. test different, most promising (noise figure) FE

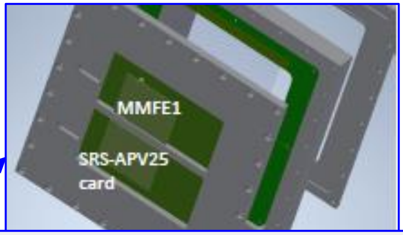
- **Boards to test read-out via VMM3 acquired**
- **Dedicated micromegas stage for comparative evaluation designed and mechanical construction started**

2. Detector version 2 designed following prescriptions for lower noise level; PCB submitted for production

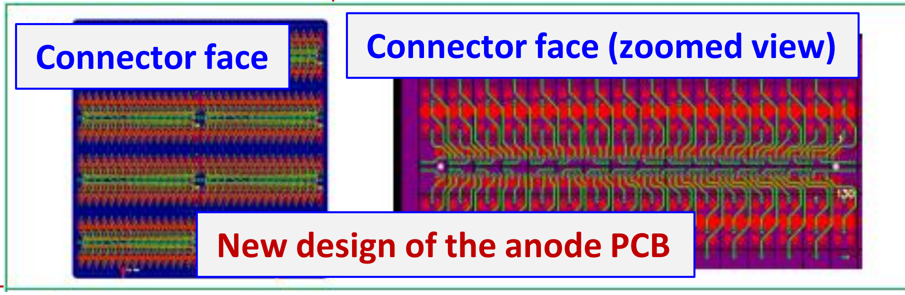


2-D Cherenkov photon distribution (background subtracted)

MMFE1 board



MM for comparative (VMM3 vs APV25) studies



Connector face

Connector face (zoomed view)

New design of the anode PCB

Particle ID: Hybrid MPGDs for RICH @ INFN

Lab activity, therefore seriously effected by the emergency status:
No access to lab after February (hoping to resume in September)

REMINDER

First months in FY2020 very productive for this task already covering all the work planned for the year:

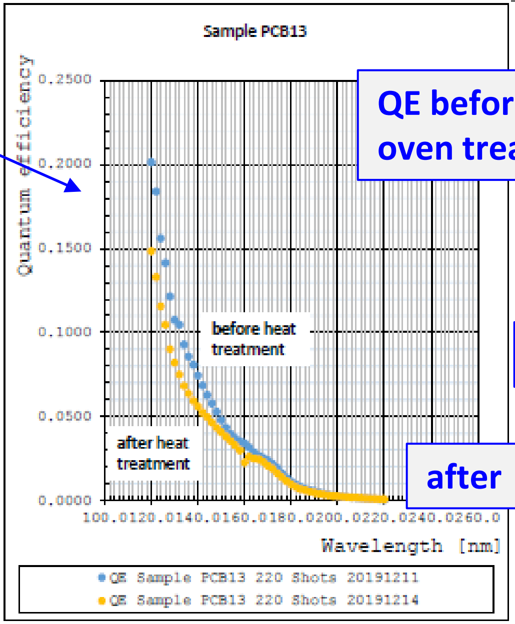
- **Novel set of samples realized and coated (spray technique)**
- **THGEMs by 2 layers attempted and abandoned because of too large gain evolution**
- **Standard performance of THGEMs with H-ND coating recovery by oven treatment**
- **QE versus number of spray shots measured**
- **QE in gas atmosphere, preliminary measurements performed**

Novel goals on top of the planned ones for the second part of FY2020

- Improvement of the oven treatment (in inert gas atmosphere)
- Absolute QE measurements in Bari and with the new CERN facility ASSET
- Further studies of the ND powder parameters that influence the QE

The preparation for these planning started and could not progress due to the emergency

substrate type	sample label	coating material	number of spray shots
THGEM	TB IX	ND	300
THGEM	TB VIII	HND	140
THGEM	TB III	HND	43
THGEM	TB VII	HND	55
THGEM	TB XIX	HND	59
THGEM	TB XI	HND	250
disc	PBC1	ND	100
disc	PBC2	ND	100
disc	PBC3	ND	200
disc	PBC4	ND	200
disc	PBC5	ND	50
disc	PBC6	HND	50
disc	PBC9	HND	25
disc	PBC7	HND	50
disc	PBC10	HND	100
disc	PBC11	HND	200
disc	PBC8	HND	400



QE before and after oven treatment

before

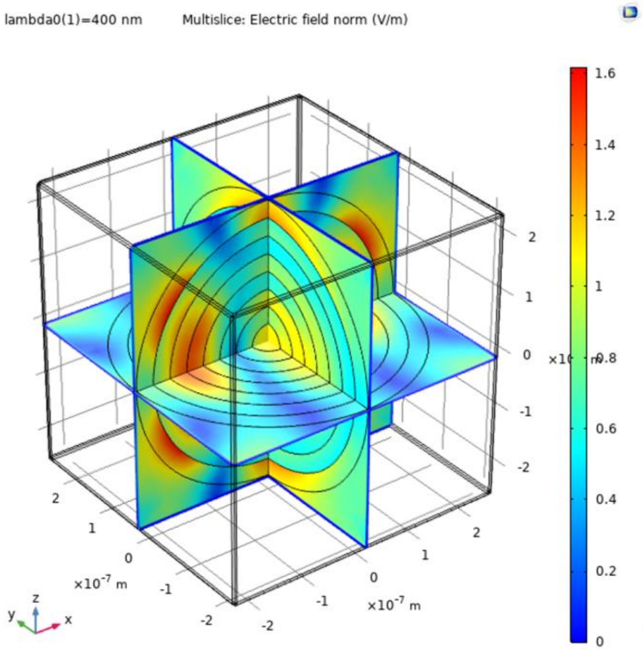
after

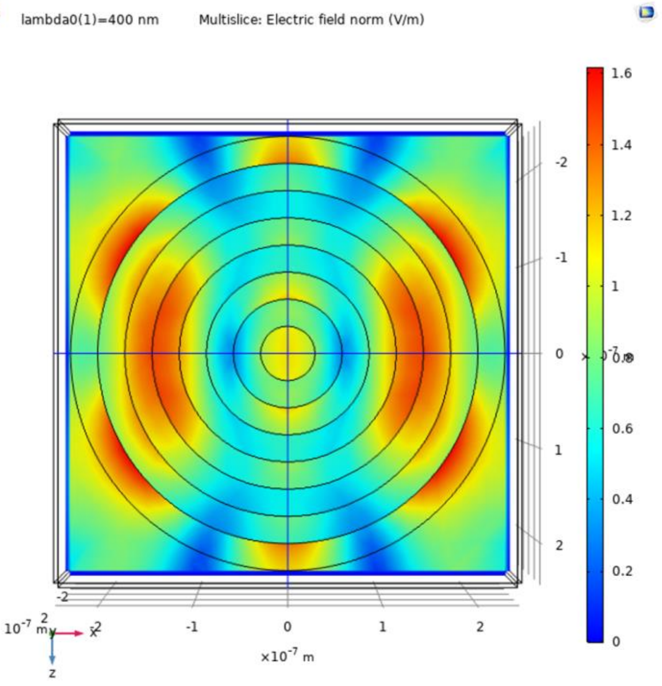
Particle ID: Large Mirrors for RICH @ SBU

- Evaporator installation complete
  - Shutdown due to COVID-19 → no commissioning possible
  - Restarted lab activities in mid-June → preparing for vacuum

Particle ID: New Radiator Studies @ SBU

- Development of FEM models in progress: propagation of planar wave (λ = 400/600/800 nm)
  - Embedded spherical layers → nano-spheres, 1 core and 7 shells
  - Alternating layers of "lossless" silica and TiO_2 of r_{max} = 240 nm and shell thickness of 30 nm





Particle ID: New Radiator Studies @ SBU

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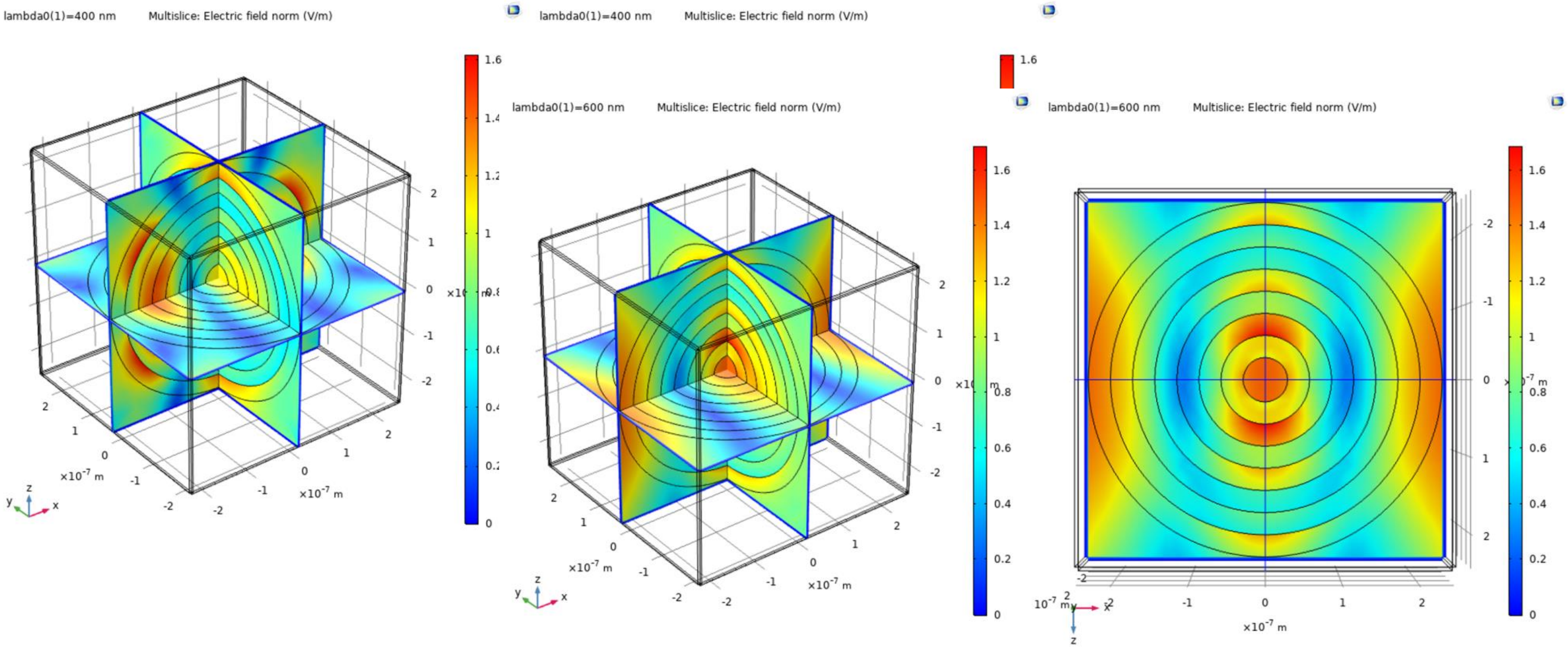
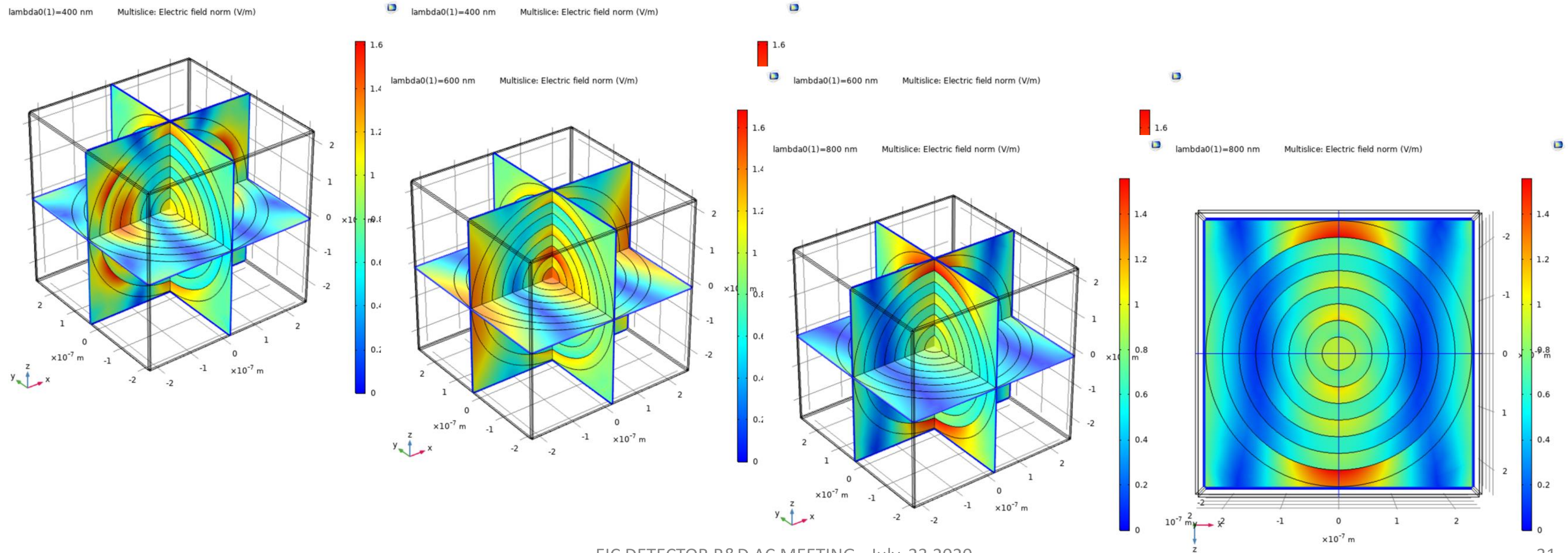


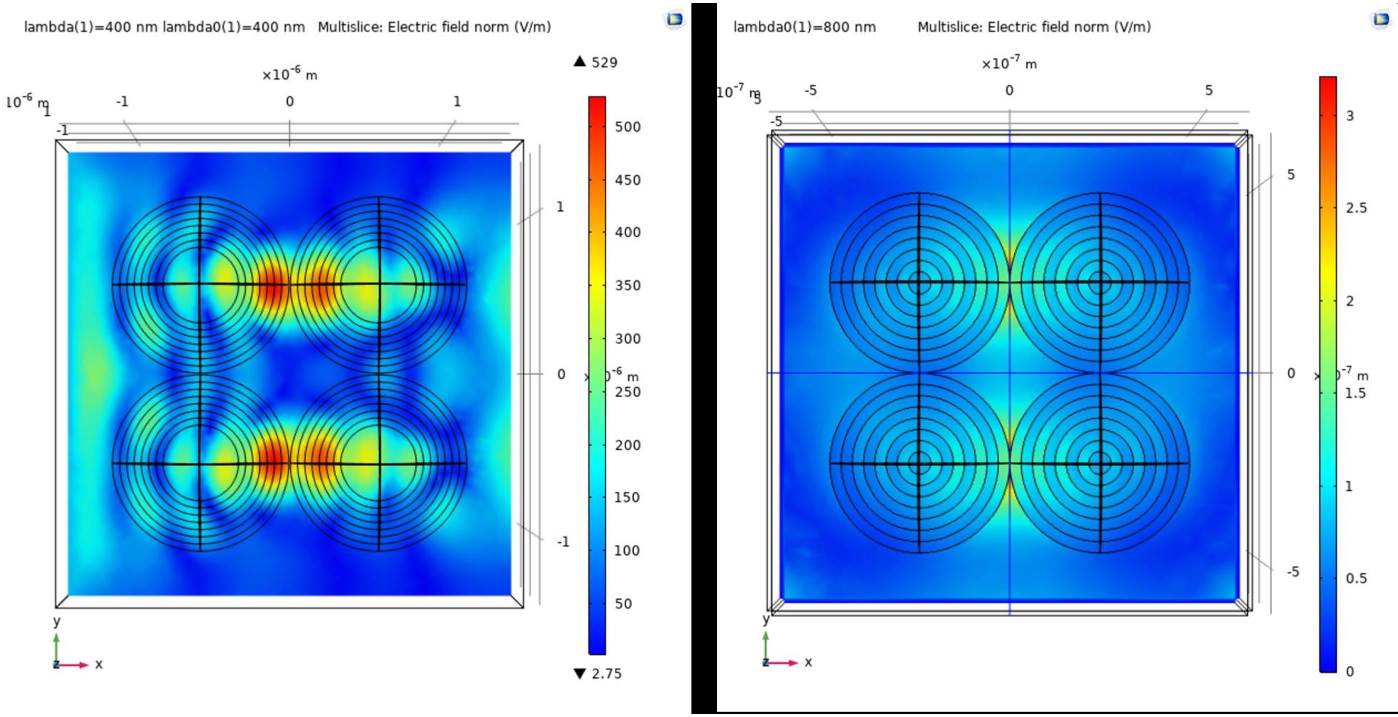
Particle ID: New Radiator Studies @ SBU

- Development of FEM models in progress: propagation of planar wave (λ = 400/600/800 nm)
  - Embedded spherical layers → nano-spheres, 1 core and 7 shells
  - Alternating layers of “lossless” silica and TiO_2 of r_{max} = 240 nm and shell thickness of 30 nm



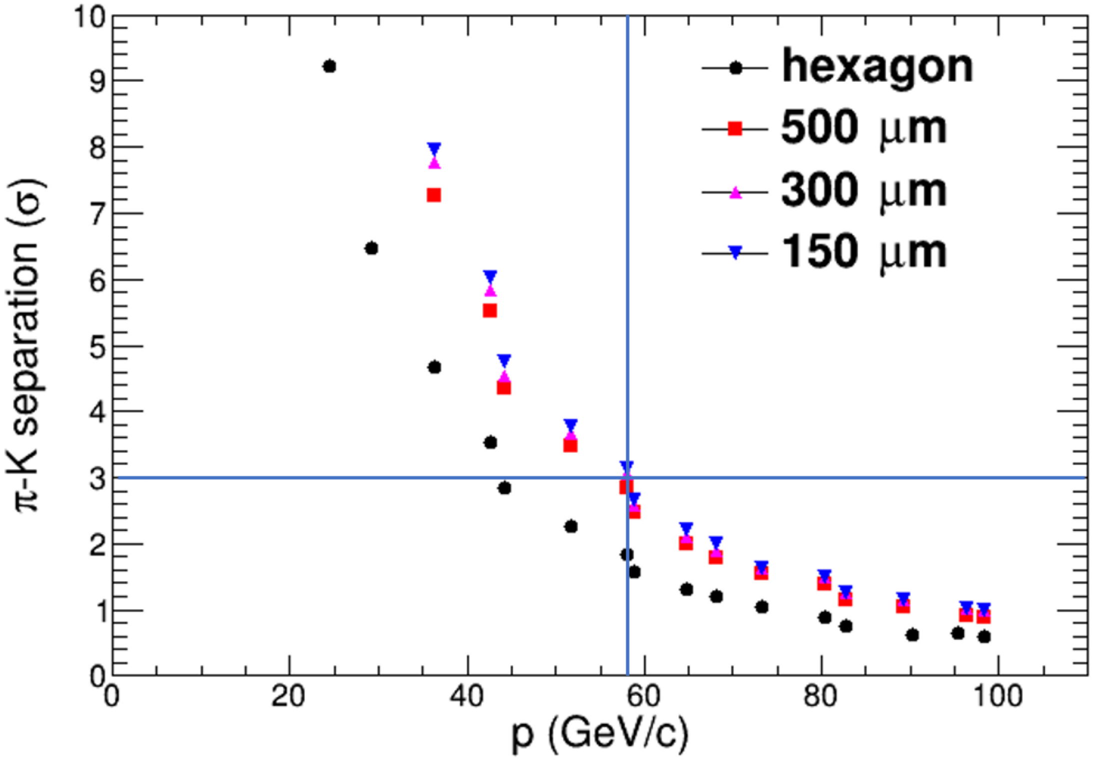
Particle ID: New Radiator Studies @ SBU

- Development of FEM models in progress: propagation of planar wave (λ = 400/600/800 nm)
  - Embedded spherical layers → nano-spheres, 1 core and 7 shells
  - Alternating layers of "lossless" silica and TiO_2 of r_{max} = 240 nm and shell thickness of 30 nm
  - 2 x 2 arrangement
  - Development of NN
  - Development of large training Sample via T-matrix formalism



Particle ID Proposal: High Pressure Ar based RICH @ SBU

- Fluorocarbons with favorable characteristics for high momentum reach RICH, e.g., CF_4
- Fluorocarbons might become limited resource due to large GWP
- We want to be pro-active → proposing to investigate alternative gasses
- Noble gasses at high pressure might mimic properties of CF_4, e.g., Ar @ 1.5 atm
- We need to investigate
  - Windowless RICH detector operable with HP-Ar
  - Photo-electron efficiency with HP-Ar
  - RICH performance with HP-Ar
    - with SBU-RICH prototype
- Investigate separation power toward higher momenta with capacitive-sharing pad readout board à la UVa



Budget Request

eRD6 Projects Completion Milestone Breakdown

❖ **End Cap Tracker – Large-area & Low-mass GEMs**

1. **Large GEM prototypes:** Our plan is to complete characterization of the two current UVa & FIT large GEM prototypes **by December 2021.**
   - ⇨ **January 2020 – July 2021:** Pursue the characterization of UVa prototypes with cosmic and x-ray setups at UVa; Complete the refurbishment of FIT prototype and upon successful outcome, characterize the detector in cosmics and x-ray setup at Florida Tech
   - ⇨ **July 2021 – December 2021:** Characterization of the two prototypes in test beam at Fermilab followed by the data analysis effort and submission of the results to a peer-reviewed journal.

2. **Complete the simulation of End Cap tracker detectors:** Full study of material budget and performances of **realistic** large area GEM in the end cap region of a EIC detector by **December 2022** including impact of the material budget of the central detector choice.
   - ⇨ **July 2020 – July 2021:** Complete the implementation of realistic detectors (currents parameters – geometries & material budget …)
   - ⇨ **July 2021 – July 2022:** Full and comparative simulation of TPC and Cylindrical uRWELL options
   - ⇨ **July 2022 – December 2022:** Complete the simulation of the central tracker detectors and submit the results to a peer-reviewed journal.

eRD6 Projects Completion Milestone Breakdown

❖ **Central Tracker Barrel MPGD Tracker:** **Fast Tracking µRWELL Layer**

1. **Single Cylindrical µRWELL prototype:** Our plan is to build and characterize in test beam one full size (smallest EIC detector diameter) single Cylindrical uRWELL prototype operating in micro-TPC mode **by December 2022.**
   - ⇨ **January 2020 – July 2020:** Complete the Mock-up design – Pursue the characterization of planar low-mass µRWELL prototypes
   - ⇨ **July 2020 – July 2021 :** Complete the design of the prototype and procurement of the parts
   - ⇨ **July 2021 – July 2022:** Complete the assembly of the prototype & investigation of the best FE electronics
   - ⇨ **July 2022 – December 2022:** Characterization of the prototype in test beam at Fermilab followed by the data analysis effort and submission of the results to a peer-reviewed journal.
2. **Complete the simulation of central tracker detector:** Study of material budget and performances of uRWELL vs. TPC in a realistic EIC detector including impact of the material budget of the central detector choice in the endcap region **by December 2022**
   - ⇨ **January 2020 – July 2020:** Start the implementation of realistic detectors (currents parameters – geometries & material budget)
   - ⇨ **July 2020 – July 2021:** Complete the implementation of realistic detectors
   - ⇨ **July 2021 – July 2022:** Full simulation of the End Cap GEMs including the impact of the material budget of the barrel detector on the performances of the end cap tracker.
   - ⇨ **July 2022 – December 2022:** Complete the full simulation of the central trackers and submit results to a peer-reviewed journal.

eRD6 Projects Completion Milestone Breakdown

- **Barrel TPC:**

TPC R&D Milestones for BNL & Yale

- ⇨ Complete optimization study of TPC readout elements (avalanche schemes, operating gases, anode readout patterns, etc.): **July 2021**
- ⇨ Complete studies on IBF vs resolution with different avalanche schemes and operating gases: **July 2021**
- ⇨ Implement improvements in mini-TPC prototype (laser calibration, readout electronics, etc.) and test in the lab: **July 2021**
- ⇨ Test various TPC components and mini-TPC prototype in the test beam at Fermilab and analyze data: **December 2022**
- ⇨ Complete initial investigation of adapting MPGD readout planes for LAPPDs to study spatial and time resolution **July 2021**

- **Hybrid MPGDs with fine space resolution for RICHs**
  - ⇨ Construction and characterization of the upgraded version of the prototype: **September 2021**
  - ⇨ An exploratory study about the configuration of the MPGD pads aiming at reducing the discharge rate: **September 2021**

- **New Photocathodes by Hydrogenated NanoDiamond (H-ND) powder for RICHs**
  - ⇨ Complete a small size prototype of a MPGD-based photon detector with hydrogenated nanodiamond power photocathode: **September 2021**

- **TPC/PID SBU**
  - ⇨ Test of bi-polar gating grid at ANL's magnet facility: **second quarter 2021**
  - ⇨ Operation of evaporator: **third quarter 2020**

eRD6 Budget Request & Money Matrix

Table 1: Fully loaded cost matrix of institutes and R&D topic for the eRD6 FY21 budgetary request

k$	μRWELL Cyl. Layer	Micromegas Barrel Tracker	TPC Readout	Forward Tracker	MPGD RICH	High Press. RICH	Total
BNL & Yale U.			79.5				**79.5**
Florida Tech	46.19			3.49			**49.68**
INFN Trieste					38		**38**
Temple U.	33.5						**33.5**
CEA Saclay		8					**8**
SBU						24.15	**24.15**
UVa	50						**50**
Total	**129.69**	**8**	**79.5**	**3.49**	**38**	**24.15**	**282.83**

Thank You

Number of institutions/labs
8

Number of People
37

Number of publications
28

We would like to thank the EIC R&D Program for all their support in making this a successful program!

Backup

eRD6 Publications

BNL publications:

[1] B. Azmoun et al. "Design Studies of High Resolution Readout Planes using Zigzags with GEM Detectors". In: *IEEE Transactions on Nuclear Science* PP (June 2020), pp. 1–1. DOI: 10.1109/TNS.2020.3001847.

[2] B. Azmoun et al. "Results From a Prototype Combination TPC Cherenkov Detector With GEM Readout". In: *IEEE Transactions on Nuclear Science* 66.8 (Aug. 2019), pp. 1984–1992. ISSN: 1558-1578. DOI: 10.1109/TNS.2019.2928269.

[3] M. Vandenbroucke et al. "A Study of "Zigzag" Strip Readout for Micromegas Detectors". In: Nov. 2018, pp. 1–4. DOI: 10.1109/NSSMIC.2018.8824702.

[4] B. Azmoun et al. "Design Studies for a TPC Readout Plane Using Zigzag Patterns with Multistage GEM Detectors". In: *IEEE Transactions on Nuclear Science* (July 2018), pp. 1–1. ISSN: 0018-9499. DOI: 10.1109/TNS.2018.2846403.

[5] B. Azmoun et al. "A Study of a Mini-Drift GEM Tracking Detector". In: *IEEE Transactions on Nuclear Science* 63.3 (June 2016), pp. 1768–1776. ISSN: 0018-9499. DOI: 10.1109/TNS.2016.2550503.

[6] Craig Woody et al. "A Prototype Combination TPC Cherenkov Detector with GEM Readout for Tracking and Particle Identification and its Potential Use at an Electron Ion Collider". In: 2015. arXiv: 1512.05309 [physics.ins-det]. URL: https://inspirehep.net/record/1409973/files/arXiv:1512.05309.pdf.

[7] B. Azmoun et al. "Initial studies of a short drift GEM tracking detector". In: *2014 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC)*. Nov. 2014, pp. 1–2. DOI: 10.1109/NSSMIC.2014.7431059.

[8] M. L. Purschke et al. "Test beam study of a short drift GEM tracking detector". In: *2013 IEEE Nuclear Science Symposium and Medical Imaging Conference (2013 NSS/MIC)*. Oct. 2013, pp. 1–4. DOI: 10.1109/NSSMIC.2013.6829463.

Florida Tech publications:

[1] Marcus Hohlmann et al. "Low-mass GEM detector with radial zigzag readout strips for forward tracking at the EIC". In: *2017 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC 2017) Atlanta, Georgia, USA, October 21-28, 2017*. 2017. arXiv: 1711.05333 [physics.ins-det]. URL: http://inspirehep.net/record/1636290/files/arXiv:1711.05333.pdf.

[2] Aiwu Zhang et al. "A GEM readout with radial zigzag strips and linear charge-sharing response". In: *Nucl. Instrum. Meth.* A887 (2018), pp. 184–192. arXiv: 1708.07931 [physics.ins-det].

[3] Aiwu Zhang and Marcus Hohlmann. "Accuracy of the geometric-mean method for determining spatial resolutions of tracking detectors in the presence of multiple Coulomb scattering". In: *JINST* 11.06 (2016), P06012. DOI: 10.1088/1748-0221/11/06/P06012. arXiv: 1604.06130 [physics.data-an].

[4] Aiwu Zhang et al. "R&D on GEM detectors for forward tracking at a future Electron-Ion Collider". In: *Proceedings, 2015 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC 2015): San Diego, California, United States*. 2016, p. 7581965. DOI: 10.1109/NSSMIC.2015.7581965. arXiv: 1511.07913 [physics.ins-det]. URL: http://inspirehep.net/record/1406551/files/arXiv:1511.07913.pdf.

[5] Aiwu Zhang et al. "Performance of a Large-area GEM Detector Read Out with Wide Radial Zigzag Strips". In: *Nucl. Instrum. Meth.* A811 (2016), pp. 30–41. DOI: 10.1016/j.nima.2015.11.157. arXiv: 1508.07046 [physics.ins-det].

INFN publications:

[1] J. Agarwala et al. "The MPGD-based photon detectors for the upgrade of COMPASS RICH-1 and beyond". In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* (2018). ISSN: 0168-9002. DOI: https://doi.org/10.1016/j.nima.2018.10.092. URL: http://www.sciencedirect.com/science/article/pii/S0168900218314062.

[2] J. Agarwala et al. "Study of MicroPattern Gaseous detectors with novel nanodiamond based photocathodes for single photon detection in EIC RICH". In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* (2019). ISSN: 0168-9002. DOI: https://doi.org/10.1016/j.nima.2019.03.022. URL: http://www.sciencedirect.com/science/article/pii/S0168900219303213.

[3] J. Agarwala et al. "Optimized MPGD-based Photon Detectors for high momentum particle identification at the Electron-Ion Collider". In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 936 (2019). Frontier Detectors for Frontier Physics: 14th Pisa Meeting on Advanced Detectors, pp. 565–567. ISSN: 0168-9002. DOI: https://doi.org/10.1016/j.nima.2018.10.185. URL: http://www.sciencedirect.com/science/article/pii/S0168900218314992.

[4] J. Agarwala et al. "A modular mini-pad photon detector prototype for RICH application at the Electron Ion Collider". In: *Journal of Physics: Conference Series* 1498 (Apr. 2020), p. 012007. DOI: 10.1088/1742-6596/1498/1/012007. URL: https://doi.org/10.1088%2F1742-6596%2F1498%2F1%2F012007.

[5] C. Chatterjee et al. "Nanodiamond photocathodes for MPGD-based single photon detectors at future EIC". In: *Journal of Physics: Conference Series* 1498 (Apr. 2020), p. 012008. DOI: 10.1088/1742-6596/1498/1/012008. URL: https://doi.org/10.1088%2F1742-6596%2F1498%2F1%2F012008.

[6] J. Agarwala et al. *MPGD-based photon detectors for the upgrade of COMPASS RICH-1 and beyond*. 2020. arXiv: 2006.10447 [physics.ins-det].

[7] F. M. Brunbauer et al. *Nanodiamond photocathodes for MPGD-based single photon detectors at future EIC*. 2020. arXiv: 2006.02352 [physics.ins-det].

SBU publications:

[1] M. Blatnik et al. "Performance of a Quintuple-GEM Based RICH Detector Prototype". In: *IEEE Trans. Nucl. Sci.* 62.6 (2015), pp. 3256–3264. DOI: 10.1109/TNS.2015.2487999. arXiv: 1501.03530 [physics.ins-det].

TU publications:

[1] M. Posik and B. Surrow. "Construction of a Triple-GEM Detector Using Commercially Manufactured Large GEM Foils". In: 2018. arXiv: 1806.01892 [physics.ins-det].

[2] M. Posik and B. Surrow. "Construction of Triple-GEM Detectors Using Commercially Manufactured Large GEM Foils". In: *Proceedings, 2016 IEEE Nuclear Science Symposium and Medical Imaging Conference: NSS/MIC 2016: Strasbourg, France*. 2016, p. 8069743. DOI: 10.1109/NSSMIC.2016.8069743. arXiv: 1612.03776 [physics.ins-det].

[3] M. Posik and B. Surrow. "Optical and electrical performance of commercially manufactured large GEM foils". In: *Nucl. Instrum. Meth.* A802 (2015), pp. 10–15. DOI: 10.1016/j.nima.2015.08.048. arXiv: 1506.03652 [physics.ins-det].

[4] M. Posik and B. Surrow. "R&D of commercially manufactured large GEM foils". In: *Proceedings, 2015 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC 2015): San Diego, California, United States*. 2016, p. 7581802. DOI: 10.1109/NSSMIC.2015.7581802. arXiv: 1511.08693 [physics.ins-det].

[5] M. Posik and B. Surrow. "Research and Development of Commercially Manufactured Large GEM Foils". In: *Proceedings, 21st Symposium on Room-Temperature Semiconductor X-ray and Gamma-ray Detectors (RTSD 2014): Seattle, WA, USA, November 8-15, 2014*. 2016, p. 7431060. DOI: 10.1109/NSSMIC.2014.7431060. arXiv: 1411.7243 [physics.ins-det].

UVa publications:

[1] Kondo Gnanvo et al. "Large Size GEM for Super Bigbite Spectrometer (SBS) Polarimeter for Hall A 12 GeV program at JLab". In: *Nucl. Instrum. Meth.* A782 (2015), pp. 77–86. DOI: 10.1016/j.nima.2015.02.017. arXiv: 1409.5393 [physics.ins-det].

[2] Kondo Gnanvo et al. "Performance in test beam of a large-area and light-weight GEM detector with 2D stereo-angle (UV) strip readout". In: *Nucl. Instrum. Meth.* A808 (2016), pp. 83–92. DOI: 10.1016/j.nima.2015.11.071. arXiv: 1509.03875 [physics.ins-det].

Yale publications:

[1] S. Aiola et al. "Combination of two Gas Electron Multipliers and a Micromegas as gain elements for a time projection chamber". In: *Nucl. Instrum. Meth.* A834 (2016), pp. 149–157. DOI: 10.1016/j.nima.2016.08.007. arXiv: 1603.08473 [physics.ins-det].

Access to eRD6 publications from the link below

https://wiki.bnl.gov/conferences/images/c/cd/ERD6_ProgressReport_202007.pdf

eRD6 Budget Request per institutions

BNL

Table 2: Budget request for TPC R&D at BNL and Yale ,including 20% and 40% reduction scenarios (FY21)

	Baseline (k$)	-20% (k$)	-40% (k$)
TPC interleaved readout boards	15	12	9
TPC avalanche structures (Micromegas, μRWELL)	5	4	3
PID interleaved readout boards	10	8	6
Technical support	12	9.6	7.2
Gas and other expendables	6	4.8	3.6
Travel	5	4	3
Total	53	42.4	31.8
Overhead	26.5	21.2	15.9
Total with overhead	**79.5**	**63.6**	**47.7**

FIT

Table 3: **Florida Tech** - FY21 budget request including scenarios with 20% and 40% reduction.

	Request	-20%	-40%
Graduate Student Stipends (2 stud.)	$27,400	$26,400	$21,816
Undergraduate Summer Stipend	$6,000	$0	$0
Travel	$6,000	$4,000	$1,400
Materials	$5,000	$5,000	$4,000
Indirect Cost Base (travel & material)	$11,000	$9,000	$5,400
Indirect Cost (48% negotiated rate)	$5,280	$4,320	$2,592
Total	**$49,680**	**$39,720**	**$29,808**

INFN Trieste

Table 4: Funding request INFN

item	cost (k$)	overhead (k$)	total (=cost+overhead) (k$)
manpower	20	4	24
traveling	5	1	6
consumables	8		8
total	33	5	38

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eRD6 Budget Request per institutions

SBU

Table 6: Funding request from **SBU** for FY21. The table includes scenarios with 20% and 40% reduction.

	Request	-20%	-40%
Transfer pads readout board	$ 3,000	N/A	N/A
GEMs	$ 1,200	$ 1,200	N/A
Compressor-/control-system	$ 7,750	$ 7,750	$ 7,750
Travel (incl. IDC)	$ 4,650	$ 2,820	N/A
Materials (incl. IDC)	$ 7,550	$ 7,550	$ 6,740
Total	$ **24,150**	$ **19,320**	$ **14,490**

CEA Saclay

Table 5: R&D at CEA-Saclay (FY21)

	Baseline (k$)	**-20% (k$)**	**-40% (k$)**
Large pad readout board	4	3.2	2.4
Travel	4	3.2	2.4
Total with overhead	**8**	**6.4**	**4.8**

Temple U

Table 7: TU funding request for FY21 with 20% and 40% reduction scenarios.

Item	Request ($)	-20% ($)	-40% ($)
Postdoc (%)	(20%) 11,274	(15%) 8,455	(15%) 8,455
Fringe benefits (25.5%)	2,875	2,156	2,156
Total Personnel	14,148	10,611	10,611
Material	1,000	1,000	1,000
Travel (Domestic)	6,000	4,000	2,000
Total Direct Costs	21,148	15,611	13,611
Modified Total Direct Costs	21,148	15,611	13,611
Overhead (58.5%)	12,523	9,133	7,963
Total Project Costs	**33,520**	**24,744**	**21,574**

UVa

Table 8: UVa FY21 budget request with 20% and 40% reduction scenario

Item	**Budget Request**	**-20% scenario**	**-40% scenario**
R&D on μRWELL with Large-Pad Readout	$5,000	$3,000	$3.000
R&D on Large-Pad & Low Capacitance Readout	$5,000	$3,000	$0,000
Design and fabrication of cylindrical μRWELL	$15,000	$15,000	$15,000
Lab Supplies & Expendables	$3,000	$2,000	$1,000
Travel (fully loaded)	$9,000	$6,000	$4,000
Undergraduate Stipend	$3,000	$2,400	$1,800
Undergraduate Summer Stipend	$6,000	$4,800	$3,600
Overhead (61%)	$4,000	$3,000	$2,000
Total	**$50,000**	**$39,200**	**$30,400**

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eRD6 Progress Report: Impact of COVID-19 on Activities

7 Critical Issues: Impact of COVID-19 pandemic

7.1 Brookhaven National Lab

7.1.1 How did the COVID-19 pandemic affect progress of your project?

BNL halted normal operations around March 20th and went into "min-safe" mode, effectively barring any scientific staff from entering the site. As a result, our group has since only been able to conduct work from home and by teleconferencing. The lab has starting a gradual/phased reopening in mid-June, but members of our group will not be permitted to return to work until mid-July. Even then, the amount of time allowable on site will be limited and telecommuting will be encouraged. At this point the impact on future work is not clear.

7.1.2 How much of your FY20 funding could not be spent due to the closing of facilities?

We received $37,500 in new funding in FY20 compared to our funding request of $75,000 (i.e., 50%). As of early June we have spent $15,777 of these funds on materials, PCB fabrication and technical support.

We had intended to use the remaining $21,723 (which includes overhead, resulting in $14,500 in spendable funds) to partially support our test beam effort that was mostly covered by our MPGD LDRD in order to test some preliminary designs of readout boards for our TPC prototype. Hopefully these funds can now be carried over into FY21 to do these tests next year.

7.1.3 Do you have running costs that are needed even if R&D efforts have paused?

No. Other than pre-existing or newly placed orders we do not have any ongoing costs during the shutdown.

7.2 Florida Tech

7.2.1 How did the COVID-19 pandemic affect progress of your project?

As the occupancy of our high-bay laboratory is low, some hardware activity could continue after the statewide stay-at-home order was lifted in Florida in early May. As of June 15, the university has resumed regular operation as long as social distancing measures and CDC guidelines are observed.

7.2.2 How much of your FY20 funding could not be spent due to the closing of facilities?

Most of the funding is for students and stipend payments were continued. Also procurement for the mechanical mock-up continued.

7.2.3 Do you have running costs that are needed even if R&D efforts have paused?

Student stipends.

7.3 INFN Trieste

The critical issues concerning the 2021 activities are related to the level of recovery of the standard working conditions at INFN by September 2020. Any incompleteness in the restoration of standard working conditions can result in further delays.

The request support for year 2021 has been kept at the minimum needed to perform the planed activities. It is centered on the needed manpower. Therefore, a reduction of the resources requested would result in an activity delay or cancellation (according to the level of the cut).

7.3.1 How did the COVID-19 pandemic affect progress of your project?

The INFN-Trieste tasks are fully based on laboratory activity seriously affected by the restrictions imposed by the pandemic emergency. Laboratory activities have been stopped at INFN Trieste and at INFN Bari at the beginning of March and restarting is expected in September. Therefore, at least 50% of the current year is characterized by forced inactivity and a large fraction of the planned work has to be moved to 2021.

7.3.2 How much of your FY20 funding could not be spent due to the closing of facilities?

A relevant fraction of the funding for consumable and travelling has not / will not be spent. In particular: consumable - 4000$ (over 8000$ assigned) not spent travelling - 5000$ (over 10000$ assigned) not spent.

7.3.3 Do you have running costs that are needed even if R&D efforts have paused?

The manpower funding of 20,000 $ has been used because the postdoc support has to be continued also in the emergency shutdown period.

7.4 Stony Brook University

7.4.1 How did the COVID-19 pandemic affect progress of your project?

The COVID-19 situation created the shutdown of all lab activities starting from mid-March in 2020. The consequence was the stop of the start-up process for the evaporator as well as the planned commissioning activities.
The planning process for testing the gating grid structure was impacted, too.

7.4.2 How much of your FY20 funding could not be spent due to the closing of facilities?

None of the spending of FY20 funding was paused. We were continuing the design of the gating grid and "only" the planning stage for the test at ANL is on hold.

7.4.3 Do you have running costs that are needed even if R&D efforts have paused?

None.

7.5 Temple University

7.5.1 How did the COVID-19 pandemic affect progress of your project?

We could not begin or complete our μRWELL μTPC prototype work. We had an initial delay due to receiving the awarded money. Once we did receive the money, The COVID-19 pandemic forced Temple U. to close their labs. Labs are expected to reopen by July and this activity can then resume.

7.5.2 How much of your FY20 funding could not be spent due to the closing of facilities?

Come July, we will have spent the money awarded to for the planar 10 cm $\times$ 10 cm μRWELL detector operating in μTPC mode.

7.5.3 Do you have running costs that are needed even if R&D efforts have paused?

Yes, the 10% partial postdoc salary.

7.6 University of Virginia

7.6.1 How did the COVID-19 pandemic affect progress of your project?

The overall impact of he COVID-19 so far was a delay by a couple of months of the planned eRD6 activities at UVa. The acquisition of μRWELL operating in μTPC mode was significantly delayed as well as the procurement of SRS-VMM electronics power supply and the zebra strips that we planned to test with the large U-V GEM prototype. The test beam plans at JLab and FNAL to complete the studies of the μRWELL prototype with X-Y strips readout has also been postponed as well. These activities are now slowly resuming and we have started to place the order for some of the items that needs to be procured.

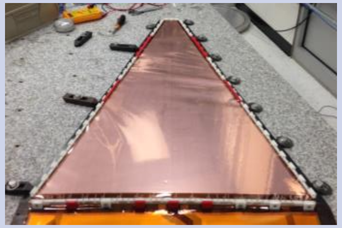
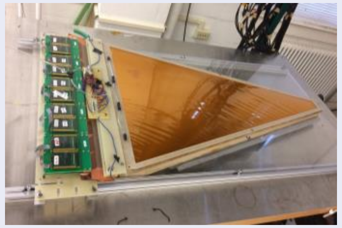
7.6.2 How much of your FY20 funding could not be spent due to the closing of facilities?

The bulk of the eRD6 money awarded to UVa for the current FY20 was for procurement of μRWELL, small GEM trackers, zebra strips and SRS-VMM electronics. As of today the order has been placed for most of these items and some of them such as the small GEM trackers have been delivered and GEMs have been assembled and tested. We used a portion of the travel money for travel to JLab during the Fall 2019 and Spring 2020 test beam in Hall D at JLab.

7.6.3 Do you have running costs that are needed even if R&D efforts have paused?

We don't have running cost that are needed while these efforts are paused.

End Cap Tracker: Summary Table of eRD6 FT GEMs

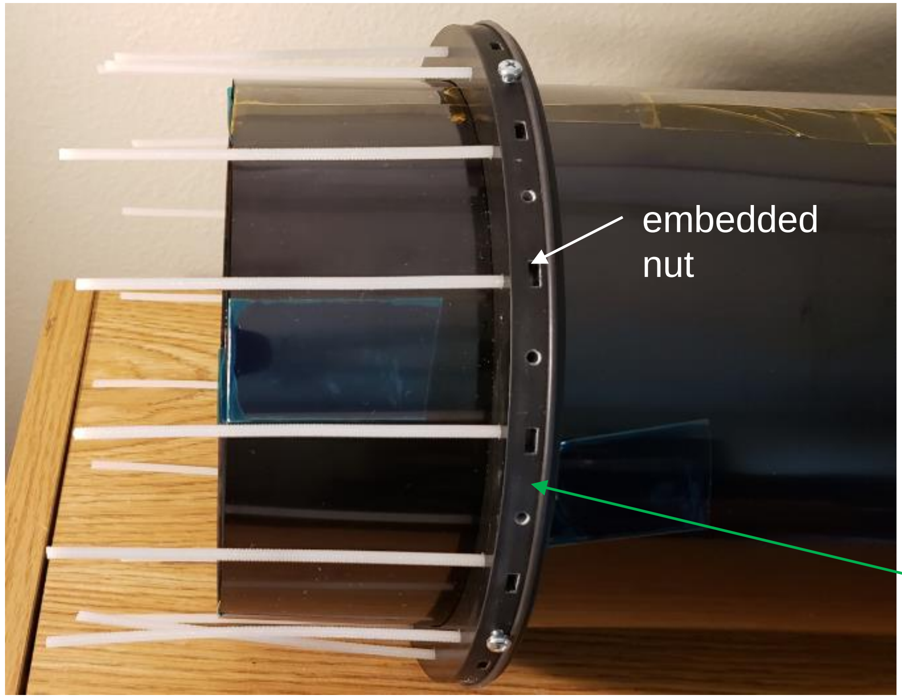
	Status of the prototype	Assembly technique	Readout technology	spatial resolution	Low mass	Dead area from support frames	Dead area in active area	FE cards connection
FIT FT-GEM 	Assembled – Technical issues – Fixes underway **(-)**	**Mech. Stretching technique - chamber can be reopened (+)**	1D Zigzag strips **(-)**	100 µm **(+) but 1D only**	**Yes (+)**	Carbon Fiber, G10 Fiber glass, metallic piece **(-)**	**No spacers (+)**	Standard - Outside active area **(+)**
UVa FT-GEM 	**Assembled – Tested in beam at FNAL (+)**	Glued frames - chamber can't be reopened **(-)**	**2D U-V stereo-angle strips (+)**	100 µm × 400 µm **(+)**	**Yes (+)**	**Fiber glass (G10) 15 mm (+)**	300 µm straight spacers grid **(-)**	**Zebra - Outside active area (+)**
TU FT-GEM 	STAR FGT Technical issues – Fixes underway **(-)**	Glued frames - chamber can't be reopened **(-)**	**2D radial-Azimuth strips (+)**	**100 µm × 100 µm (+)**	**Yes (+)**	(G10) 15 mm but FE cards on side **(-)**	50 µm Kapton rings **(-)**	Outside active area But FE on side **(-)**?

FLORIDA TECH

Barrel Fast Tracking Layer: Cylindrical µRWELL @ FIT

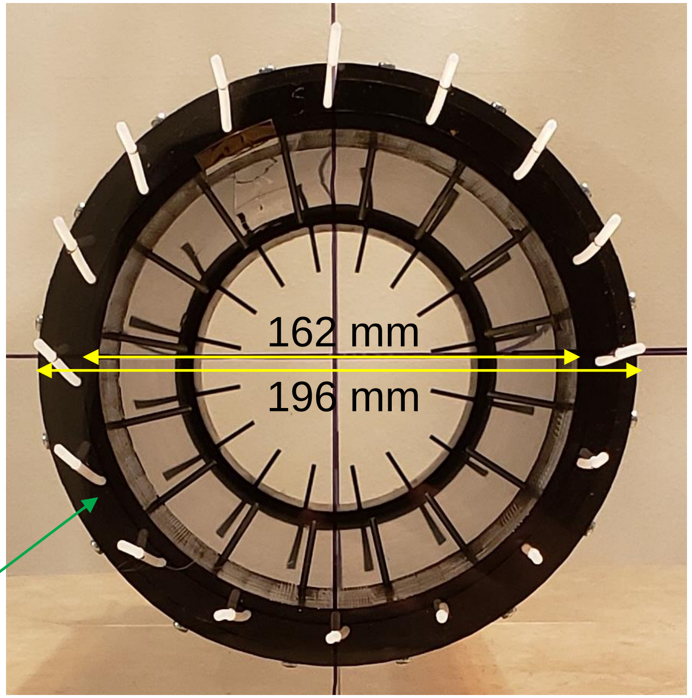
Components for <u>Mechanical Mock-up</u> of a Small Layer:

endring assembly with nylon stretching rods and O-ring (side view)



endring assembly with nylon stretching rods (end view)

Drift spacer ring



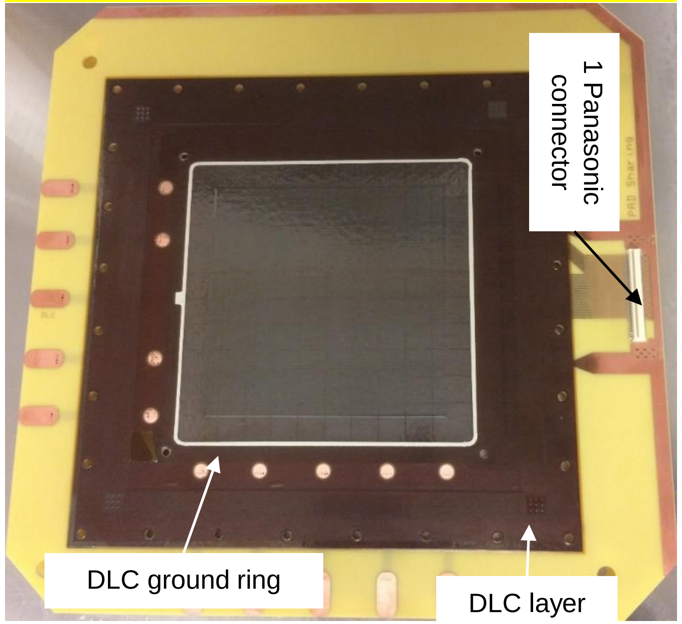
Fast Tracking µRWELL Layer: Capacitive-Sharing Pad Readout

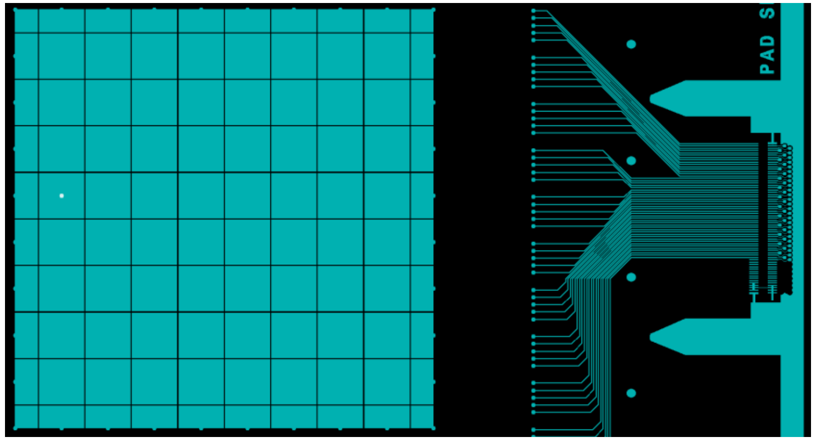
Prototype

5-layers capacitive-sharing large-pad readout:

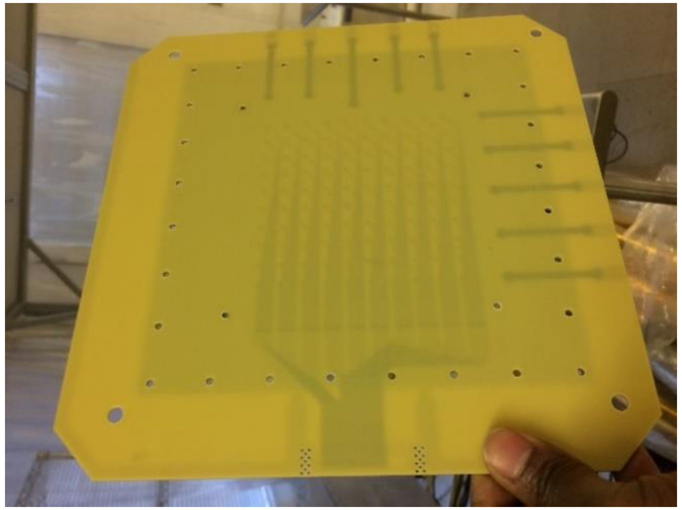
- Top layer pad pitch: 0.625 mm × 0.625 mm **with 0.1 mm inter-pad**
- Bottom pad pitch (readout pad): 10 mm × 10 mm **with 0.1 mm inter-pad**
- DLC layer with surface resistivity 10 - 20 MΩ

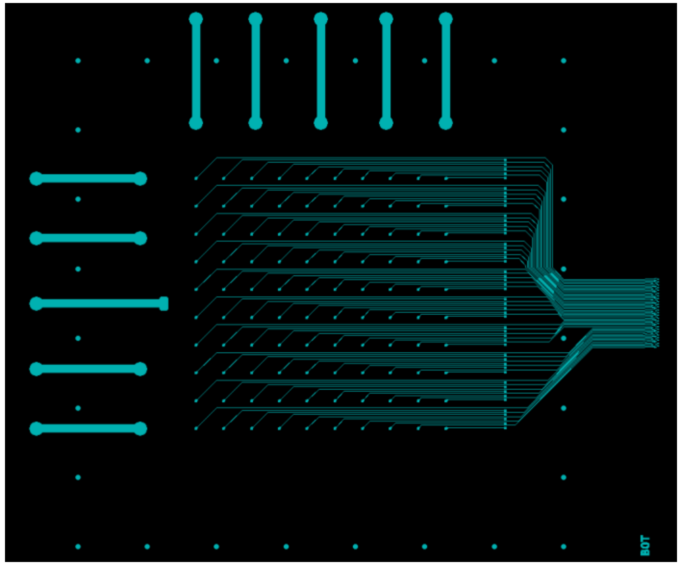
Capacitive-sharing large-pad board





Back side with traces to the connector

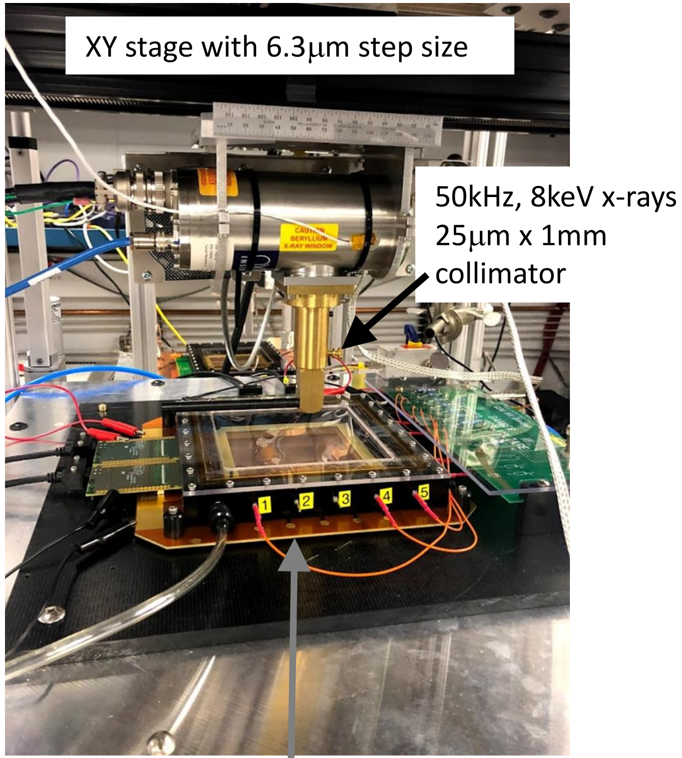




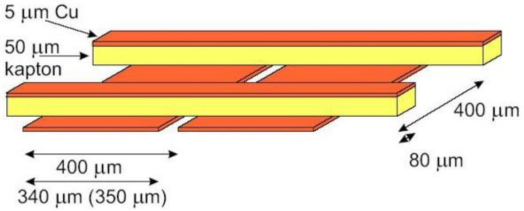
Capacitive-sharing large-pad prototype in x-ray setup

Central Tracker: TPC R&D @ BNL

❑ Characterizing New Collimated X-ray Source



COMPASS 2D Microstrip r/o



Detector Response